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THESIS

A PROPOSED FIRE SUPPORT COMMUNICATION ARCHITECTURE FOR EXTENDING THE LITTORAL BATTLESPACE (ELB) ADVANCED CONCEPT TECHNOLOGY DEMONSTRATION (ACTD) '01

by

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June 1999

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13. ABSTRACT
Extending the littoral battlespace (ELB) is vital to the United States Navy and Marine Corps. Fast, accurate, and reliable fire support will continue to be essential to the execution of Operational Maneuver From The Sea (OMFTS) and Ship-To-Objective Maneuver (STOM). The emergence of new technology has made these concepts possible. Technology will allow Marines to reach their objectives faster and farther then ever before. Information gathering, dissemination, and targeting will be key factors to the success of these new concepts.

The development of low earth orbiting satellites that provide a seamless command, control, communications and intelligence (C4I) network will be necessary for ELB. This network will provide worldwide coverage, emphasize light forces with the ability to connect to larger forces and have a near zero footprint. The emerging communication architectures must have the capacity for voice, data, and video handling from high to narrow bandwidth. Developing a "light" communications architecture that supports these emerging concepts will allow ELB to be responsive for joint operations in the twenty-first century.

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ABSTRACT

Extending the littoral battlespace (ELB) is vital to the United States Navy and Marine Corps. Fast, accurate, and reliable fire support will continue to be essential to the execution of Operational Maneuver From The Sea (OMFTS) and Ship-To-Objective Maneuver (STOM). The emergence of new technology has made these concepts possible. Technology will allow Marines to reach their objectives faster and farther then ever before. Information gathering, dissemination, and targeting will be key factors to the success of these new concepts.

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LIST OF ABBREVIATIONS AND ACRONYMS

AADC	Area Air Defense Commander
AAV	Amphibious Assault Vehicle
ACTD	Advanced Concept Technology Demonstration
ADP	Air Defense Plan
AFATDS	Advanced Field Artillery Tactical Data Systems
AODC	Attitude and Orbit Determination and Control
ATM	Asynchronous Transfer Mode
ATO	Air Tasking Order
B-ISDN	Broadband Integrated Services Digital Network
BW	Bandwidth
C&DH	Command and Data Handling Subsystem
C2	Command and Control
C4ISR	Command, Control, Communications, and Computers, Intelligence, Surveillance, and Reconnaissance
CATF	Commander Amphibious Task Force
CDMA	Code Division Multiple Access
CFF	Call-for-Fire
CINC	Commander-in-Chief
CNO	Chief of Naval Operations
CLF	Commander Landing Forces
COCC	Constellation Operations Control Centers
COE	Common Operating Environment
COP	Common Operational Picture
COTS	Commercial off the Shelf
CSCI	Commercial Satellite Communications Initiative
CVBG	Carrier Battlegroup
DASC	Direct Air Support Centers
DII	Defense Information Infrastructure
DISA	Defense Information Systems Agency
DOD	Department of Defense
DTG	Date Time Group (DOD)
EIRP	Effective Isotropic Radiated Power
FACP	Field Artillery Command Posts
FCC	Federal Communication Commission
FDMA	Frequency Division Multiple Access
FDC	Fire Direction Centers
FSCL	Fire Support Coordination Line
FSE	Fire Support Element

GCCS	Global Command and Control System
GDN	Globalstar Data Network
GEO	Geostationary-Earth-Orbit
GOCC	Ground Operations Control Center
GPS	Global Positioning System
GSL	GigaLink Satellite Link
GUI	Graphical User Interface
ECOC	Enhanced Combat Operations Center
EDAT	Engineering Diagnostic and Trending
ELB	Extending the Littoral Battlespace
F&T	Fires and Targeting
FEB-A	Fleet Battle Experiment "Alpha"
FBE-B	Fleet Battle Experiment "Bravo"
FBE-C	Fleet Battle Experiment "Charlie"
FSCC	Fire Support Coordination Center
INMARSAT	International Marine/Maritime Satellite
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISL	Inter-Satellite Link
JCATS	Joint Combat and Tactics Simulation
JCM	Joint Conflict Model
JOA	Joint Operations Area
JSTARS	Joint Surveillance Targeting Attack Radar System
JTIDS	Joint Tactical Information Distribution System
JTS	Joint Tactical Simulation
JVMF	Joint Variable Message Formats
KB	Kernel Blitz
KBPS	Kilobits Per Second
LAN	Local Area network
LAV	Light Armored Vehicle
LAWS	Land Attack Warfare System
LCAC	Landing Craft Air-Cushioned
LCU	Lightweight Computer Unit
LEO	Low Earth Orbit
LF	Landing Forces
LOS	Line-of-Sight
MAGTF	Marine Air Ground Task Force
MEB	Marine Expeditionary Brigade
MEF	Marine Expeditionary Force

MEO	Medium Earth Orbit
MEU	Marine Expeditionary Unit
MILSATCOM	Military Satellite Communication
MOE	Measure of Effectiveness
NFA	No Fire Areas
NOCC	Network Operations Control Centers
NSFS	Naval Surface Fire Support
NWCS-P	Naval Surface Fire Support Weapons Control System-Prototype
OMFTS	Operational Maneuver From the Sea (OMFTS)
ONR	Office of Naval Research
OPNOTES	Operational Notes
OTH	Over-the-Horizon
PalmELVIS	Palm Enhanced Linked Virtual Information System
PCS	Personal Communication System
POSREP	Position Report
PSTN	Public Switched Telephone Network
QPSK	Quadrature Phase Shift Keying
RAM	Random Access Memory
RLT	Regimental landing Team
ROE	Rules of Engagement
ROF	Ring of Fire
SACC	Supporting Arms Coordination Center
SB	Scanning Beam
SITREP	Situation Report
SOCC	Satellite Operations Control Center
SPMAGTF	Special Purpose Marine Air-Ground Task Force
STOM	Ship-To-Objective Maneuver
TACC	Tactical Air Command Center
TCIM	Tactical Communications Interface Module
TCP/IP	Transmission Control Protocol/Internet Protocol
TDMA	Time Division Multiple Access
TT&C	Telemetry, Tracking, and Command
USMTF	United States Message Text Formats
WAN	Wide Area Network

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EXECUTIVE SUMMARY

The doctrinal concepts of "Operational Maneuver From The Sea" (OMFTS) and "Forward...From the Sea" adopted by the United States Marine Corps and Navy have shifted the focus of U.S. maritime strategy from open-ocean operations to littoral operations penetrating deep inland. This new littoral environment combined with new technology, including the Advanced Amphibious Assault Vehicle (AAAV) and the MV-22 Opsrey, allows for deeper and faster maneuver to objectives. This ability will impose new demands on littoral fire support and communications.

The appearance of new technology on the commercial market such as cellular/satellite handsets and palm held computers have made personal computing and the ability to instaneously transmit messages around the world possible. Currently, the Marine Corps and Navy lack the ability for Marines to transmit naval surface fire support requests to ships from 200 miles inland to 100 miles "over-the-horizon" (OTH) as outlined by the OMFTS and "Ship-To-Objective Maneuver" (STOM).

This thesis explores the possible benefits of using a low earth orbiting (LEO) satellite constellation for a communication backbone to request naval surface fires for great distances ashore. It will attempt to use a LEO system to "Extend the Littoral Battlespace" (ELB).

It investigates the capabilities and limitations of three LEO systems, including bandwidth size, and time latency to span OTH distances that challenge an OMFTS forces' ability to communicate to their sea based fire support center. It also uses modeling and simulation techniques to find communication delay times and how these

results affect achieving objectives compared to current communication architectures. In addition, it makes a recommendation for future fire support communications.

I. INTRODUCTION

A. PURPOSE OF THESIS

This thesis proposes a viable fire support communications architecture for the Extending the Littoral Battlespace (ELB) Advanced Concept Technology Demonstration (ACTD) 2001. This architecture supports the United States Marine Corps doctrine of Operational Maneuver From The Sea (OMFTS). The research will analyze communication and technology requirements needed to build an operational fire support architecture to support OMFTS operations from 100 nautical miles at sea to 200 miles ashore.

1. Overview

The United States Marine Corps concept for power projection ashore in the ever increasing littoral areas is described in its warfighting concept of "Operational Maneuver From The Sea" (OMFTS). [Ref. 1]

2. Littoral Doctrine

The Marine Corps doctrine of OMFTS is an overarching concept serving as an umbrella for the tenets of "Ship-To-Objective Maneuver" (STOM), "The MAGTF in Sustained Operations Ashore", "Beyond C2", and "Advanced Expeditionary Fire Support." [Ref. 2,3,4 and 5] These combined concepts will Extend the Littoral Battlespace (ELB). ELB seeks an expeditionary force that is light, agile, potent, distributed and integrated. If this is achieved, the force will have enormous situational awareness and be supported by precise remote and loitering fires connected by a robust information infrastructure. By possessing a light, agile and potent expeditionary force,

the United States Marine Corps and Navy will be prepared to conduct operations in the littorals in all parts of the world.

a. Operational Maneuver from the Sea (OMFTS)

OMFTS is a response to both danger and opportunity. Danger is derived from the inherent chaos found in the littorals consisting of a clash of forces with national aspirations, religious intolerance, and ethnic hatred. Opportunity comes from the significant enhancements in information technology, battlefield mobility, and the lethality of conventional weapons. [Ref. 1] It is comprised of many elements. OMFTS focuses on an operational objective vice establishing waves for beach build-ups and it uses the sea as a maneuver space. Pitting friendly strengths against enemy weaknesses will generate overwhelming tempo and momentum. This new doctrine also emphasizes intelligence, deceptions and flexibility, and integrates all organic, joint, and combined assets.

Command and Control systems will be very different than the processes developed for traditional approaches to amphibious assault. Communications systems will provide warfighters with control over information they need. They will also provide all units with the ability to communicate over-the-horizon. Successful execution of OMFTS will change fire support. Mobility ashore will improve dramatically by increasingly taking advantage of sea-based fires. To improve responsiveness and support, fire support coordination must be streamlined. Finally, to provide effective fires, forces afloat require the ability to deliver long range fires with greater accuracy and lethality.

In the future, new technologies will give small units greater combat power. This will be accomplished through improvements in the precision of long range

weapons, greater reliance on sea-based fire support, and over the horizon communications. These elements make OMFTS possible and will revolutionize amphibious warfare.

b. Ship-to-Objective Maneuver (STOM)

STOM (see Figure 1) is a tactical concept for the actual amphibious operations discussed in OMFTS. It uses maneuver warfare concepts to extend the littoral battlespace. Landing forces will be capable of penetrating objectives deep inland from over the horizon. The tenets of maneuver warfare combined with the principles of OMFTS and STOM are a major evolution in amphibious warfare.

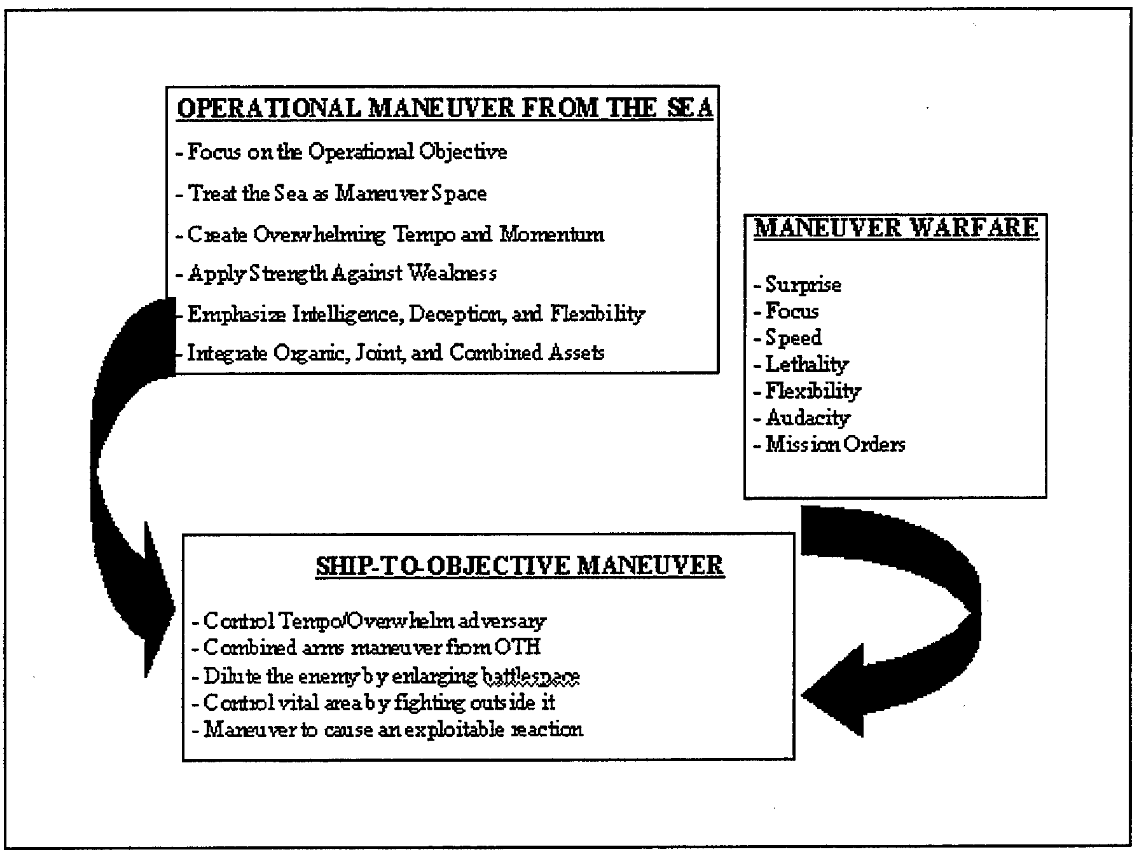

Figure 1. Ship-to-Objective Maneuver. [Ref. 2]

The improvements in mobility will free the commanders from the constraints of securing a large beachhead. This allows the landing force to focus on the enemy and begin maneuver from over the horizon. The combination of the maneuver warfare principles and emerging technologies will improve the naval force's combat effectiveness.

The cornerstone of STOM is the projection of combined arms teams ashore. These combined arms teams will rely heavily on sea-based command and control, logistics, and fire support. Landing forces vulnerabilities and footprint ashore will be greatly reduced by seabasing most supporting fires. This will improve freedom of maneuver thus enabling the naval force to project ashore combat formations that are leaner, lighter, and more effective.

Successful implementation of the STOM concept will require improvements in command and control, and fires. Command and control allows a commander to recognize what needs to be accomplished and communicates those actions to ensure mission completion. Maneuver warfare stresses decentralized execution with subordinate commanders exercising maximum latitude possible in performing assigned missions. This C2 system must provide commanders, at all levels, a common operational picture and connectivity to monitor execution and influence events when necessary. [Ref. 2]

Fire support of STOM must provide immediate and responsive high volume suppression and neutralization fires for all levels of the landing force. *Unit commanders at all levels* will call for fire support and will be capable of controlling the fires of organic and supporting arms. This fire support system must be capable of

providing highly accurate and lethal long-range fires, and an "around the clock" all weather capability. Fire support agencies must respond for fire with sufficient speed and accuracy to support this highly mobile and maneuvering landing force. STOM will be a success by combining the foundations of maneuver warfare and the enabling technologies of today and tomorrow. This concept will give landing forces new capabilities never thought possible and will revolutionize amphibious operations.

3. Scope of Thesis

This thesis is a study that presents naval surface fire support requirements to extend the littoral battlespace and architecture requirements for over-the-horizon communications for naval expeditionary fire support. It also discusses three commercial satellite systems capable of providing a communications backbone for fires, and selects one architecture modeled in a PC based network design tool and simulated in a combat simulation software. This thesis examines the following research questions:

1. Primary research question: What communication architecture currently being developed and possible future ones will best provide the means to transport targeting data for supporting fires in the most efficient manner to extend the littoral battlefield?
2. What communication architecture can be developed to support the concepts of OMFTS and STOM from the individual Marine to a MEF size fire support element?
3. What are the bandwidth requirements and what comprises this bandwidth for fire support data in these new operational concepts?

4. What have been the fire support communication requirements for a MEU size force based on new tactics as performed in Urban Warrior, Hunter Warrior, and Extending the Littoral Battlefield ACTD 1999?

5. What are the comparisons of the capabilities and limitations that the LEO/MEO companies can provide?

This thesis is limited to reviewing and analyzing three commercial satellite systems that could be used as a communications backbone for advanced expeditionary fire support. One will be recommended for supporting naval surface fires to support the ELB Advanced Concept Technology Demonstration (ACTD) 2001. It assumes the reader has a working knowledge of advanced warfighting concepts and communications terminology.

B. RESEARCH METHODOLOGY AND ORGANIZATION

1. Research Methodology

This thesis was initiated to possibly assist the Office of Naval Research (ONR) and the United States Marine Corps C4I and Architectures Requirements Division for ELB ACTD 2001. Sources of information for this research were literature searches conducted throughout Department of Defense (DOD) and commercial industries. Information from classes attended throughout the Naval Postgraduate School and interviews and discussions conducted with subject matter experts while on an experience tour at ONR were also used.

2. Organization

This thesis is organized as follows:

a. Chapter II

Chapter II discusses extending the littoral battlefield concepts and requirements. It reviews the capabilities sought for ELB ACTD 1999 and ACTD 2001. The technical challenges of these ACTD's are presented and ACTD '99 is discussed in detail. The communication requirements and problems for naval surface fires to support ELB, OMFTS, and STOM are introduced.

b. Chapter III

Chapter III defines naval surface fire support. It examines the process and procedures of naval expeditionary fire support for future warfighting concepts. Systems currently being used and future ones are introduced. Warfighting experiments such as Hunter Warrior and Fleet Battle Experiments are reviewed and lessons learned are discussed.

c. Chapter IV

Chapter IV presents three satellite systems (Globalstar, Iridium, and Teledesic) and their ability to provide a communications backbone for fire support. A brief description of each constellation covering communication structure, orbits, and satellite characteristics will provide the general knowledge necessary to develop a mental picture of each system concept. The focus will be a comparison of each system using the ELB ACTD requirements to determine the best constellation support for ELB, OMFTS, and STOM.

d. Chapter V

Chapter V describes the use of a software based PC modeling tool, Extend, to model the three commercial satellite systems combined with a baseline naval expeditionary fire support communications architecture. This architecture will support ELB, OMFTS, and STOM employment schemes. The results of this model, time latency, bandwidth, collision count, and successful messages delivered, will be used as input into the combat simulation runs for effects on mission accomplishment.

e. Chapter VI

Chapter VI describes the use of the high-resolution model Joint Combat and Tactics Simulation (JCATS). First, a run is conducted using current fire support techniques and communication architectures. Communication delay times are derived from the PC based modeling done for current procedures. This simulation run is then compared to another run based on future communication architecture for naval fires. These two runs are compared to find the effects that the different architectures have on mission accomplishments.

f. Chapter VII

This final chapter presents the final conclusions drawn from the research and provides recommendations for further study in this area.

II. EXTENDING THE LITTORAL BATTLESPACE

A. BACKGROUND

Extending the Littoral Battlespace (ELB) incorporates the concepts of OMFTS, Forward...From the Sea, Joint Vision 2010, STOM, and Advanced Expeditionary Fire Support. The Office of Naval Research (ONR) established the Advanced Concepts Technology Demonstrations (ACTD) for ELB from a Broad Agency Announcement dated May 7, 1997. The concept of an ACTD is a new approach to provide users with detailed interactions early in the developmental process, and as an effective means of getting capabilities rapidly into the field at reduced costs. The primary objective is to accelerate and facilitate application of mature advanced technologies to solve important military problems and thereby providing operational capabilities that will make a difference to the warfighter. [Ref. 6]

B. OBJECTIVES

The objective of the ELB ACTD is to demonstrate the military utility of a revolutionary concept for joint expeditionary warfare enabled by advanced technology. [Ref. 7] Combat units with multiple weapon systems will be integrated with command elements to defeat any adversary in the 21st century in an extended littoral battlespace. The resulting ELB ACTD will be a complete, end-to-end capability to perform four key functions: Communications, Command and Control (C2), Sensing, and Fires and Targeting. Program objectives will be achieved through a series of limited technical experiments leading up to the two major operational demonstrations. A Marine Expeditionary Unit (MEU) size element comprising of 5-10 ships, 30 armored vehicles,

30 fixed/rotary wing aircraft, and 2,000 Marines will be used for the demonstrations. The capabilities must be scalable up to a Marine Expeditionary Force (MEF).

ELB ACTD '99 took place in April 1999 of the coast of San Diego, California. The objective of this ACTD was to demonstrate a system that integrates the core capabilities in four areas (Communications, C2, Sensing, and Fires and Targeting) in a military useful, user-friendly system. Areas examined include a flattened, rapid, webbed, distributed C2 process and an order of magnitude improvement in combined fires response time.

ELB ACTD 2001 will build upon the results and developments of the ACTD '99. A system with more complete capabilities and improved robustness will be achieved for the '01 ACTD. If successful, the system may be deployed to an operational unit and additional systems procured.

These systems must be capable of supporting a MEF size element consisting of 50 ships, 425 armored vehicles, 350 fixed/rotary wing aircraft, and 50,000 Marines operating from over 100 miles at sea to 200 miles inland. Responsive sensing, communications, decision-making, and firepower over this extended area are the keys to the overall effectiveness of the ELB concept. [Ref. 7] Small deployment operations should be possible with near-zero infrastructure.

C. CONCEPT OF OPERATIONS

The ELB demonstrations exploit the operational concept of "Forward...From the Sea" and OMFTS. They seek to demonstrate a seamless command structure between afloat and ashore units thus allowing peer-to-peer communications and command by exception. Small units ashore will engage targets from greater distances, calling in

supporting fires from weapon platforms at sea or loitering weapons. Forces will operate in wider dispersed formations in a non-linear fashion, and will be capable of massing fires rapidly from dispersed locations. These units will be able to request fires from well beyond the line-of-sight of communications.

A communications architecture and fire support capability designed to support small combat units will require a flattened informational structure. Teams will seek to avoid direct firefights and will rely upon remote weapons to engage the enemy. Survivability is increased by the employment of numerous small, stealthy teams since they produce a smaller target.

D. ELB NARROWBAND COMMUNICATIONS

Communications systems for ELB will supplement and complement existing USMC/USN communication and information systems. The ELB demonstrations will attempt to achieve two major areas of improvements to make OMFTS and "Forward...From the Sea" possible. One will be a responsive, timely, narrow-band "cellular-like" voice and data to and from distributed ground forces and weapons over the entire area of operations. This area of operations is extended to cover approximately 300 miles, 200 miles inland and 100 miles over the horizon. The second area the demonstrations will investigate is a wide-band service. This service will be used by distributed command and control elements, the warfighting CINCs, as well as intelligence surveillance reconnaissance elements. This research will address the narrow-band capabilities and requirements to provide a rapid and responsive naval fire support architecture.

1. Challenges

There are many technical challenges to delivering the desired system for ELB. The first challenge is the distance to be covered by this communication architecture for naval surface fire support. In the past, naval gunfire support has been achieved through the use of line-of-sight (LOS) or high frequency communications. Achieving networked fire support communications over a swath of 300 miles will be difficult using existing communications equipment. Many links, limited to approximately 20 miles (LOS), would be needed. These links present multiple points of failures and each site must be defended which takes more manpower. The use of a commercial, cellular based system would overcome this distance challenge but a cellular system may not be available in all areas of operations. A spaceborne system such as a low earth orbiting (LEO) constellation or an airborne system will overcome the distance problem. These space systems commonly provide low bandwidth (2.4-9.6 KBPS), however future systems should provide more bandwidth. Bandwidth problems arise with the combination of supporting multicast and "push and pull" data from the dismounted warriors. There could also be a problem with "busy" signals. Though these potential difficulties exist today, they can be overcome by the use of a narrow-band "cellular-like" system. [Ref. 6]

Existing military satellite communications and hybrid military/commercial systems such as INMARSAT are useful, they cannot fulfill the OMFTS firesupport requirements. The most important reason that these systems would not meet the desired characteristics of the narrow-band network is that military satellite communications were not designed to support a large number of individual warriors.

Another challenge that has to be conquered is the achievement of an integrated network. Important issues for this integrated network such as the ability of the communications equipment to support both voice and data and the possibility of multicasting have to be resolved. Also, the system has to be able to integrate Internet Protocol (IP) addressing with cellular/PCS addressing and be incorporated into legacy systems. This challenge of an integrated distributed network must be met for the reality of a narrow-band system to take shape.

The power requirements, battery usage, and weight of the equipment are additional challenges. The fire support system is designed to support small, dismounted "hunter-killer" teams. These teams will need a lightweight unit for connectivity into the fire support network. To achieve this, a low battery power requirement will be necessary for a hand-held digital personal computer and transmission media. The desired system will be small (less than 1 kg) and a power requirement of less than 1-5 watts during transmission. This equipment must be configured to wear on the body.

This integrated fire support network must also meet the challenge of being operated in various terrain. This system has to be capable of communicating in terrain as dense as jungle canopies, as difficult as mountainous areas, and as open as desert terrain. Also, this new communication equipment must be able to be operated in an urban environment. Though current systems have difficulties communicating in all of these environments, future technological advances may be leveraged to meet these challenges.

The emergence of personal communication systems (PCS) has made communicating worldwide on a hand-held terminal possible. The initial introduction of these systems was cellular wireless technology thus limiting communications to areas

where "cells" were located. The introduction of LEO constellations provides a new form of PCS. These systems will be able to communicate in all environments because of the satellite constellation footprints and coverage. Instant, worldwide communications will be possible.

2. Desired Capabilities

ONR has established the desired capabilities of the narrow-band communications system for both the ACTD's 1999 and 2001. The ACTD 2001 will build on the results from ACTD '99 and seek to expand the scale of operations from a MEU size element up to a MEF size. Regardless of demonstration, the narrow-band system will interconnect small-deployed units. This "cellular" system will be deployed to fire team leaders (i.e., 2-3 per squad) and use small hand-held terminal devices that can receive digital data from GPS and from target location devices. [Ref. 8] This terminal device must be able to support the following applications:

* Calls for fire
* Medevac
* Resupply requests
* Forward observer reports
* Situation awareness
* Commands and other directions
* Weather reports
* Very low resolution map overlays
* Position and ID reporting

a. ACTD '99

The ACTD '99 (Phase 1) system seeks the capability to support 100-200 handsets with the capability to connect to each other and to the Enhanced Combat Operations Center (ECOC). ONR's request for proposals state that the connection times for these users should be less than 15 seconds and the digital queuing/time latency less than one second. Also, the data rate after error detecting/correcting coding must be greater than 2.4 kbps. For the Phase 1 demonstration, digital voice and data may be separate connections (i.e., a handset may be used for voice or for data but not at the same time). [Ref. 8]

b. ACTD '01

The ACTD '01 (Phase 2) system should include all of the objectives of the Phase 1 system and be capable of supporting a single MEU with the ability of scaling up to a MEF. The Phase 2 system must be able of supporting 200 to 300 narrow-band users with the ability to connect to each other and to the ECOC. The system will be more data-centric than in Phase 1 with the ability to "push and pull" data over a single connection. Also, it must be capable of interconnecting narrow-band and wide-band systems providing voice, email, and file transfers. Finally, this system must be able to multicast and not be a strict point-to-point system. [Ref. 6]

c. Notional Operational Architecture

The ELB operational architecture (see Figure 2) will incorporate current USMC/Navy communications and information systems. It will also provide the two additional capabilities of the narrow-band "cellular" system for dismounted distributed ground forces and wide-band services among distributed command and control elements.

This ELB communication architecture is an ensemble of systems in which no one system will provide all connectivity and services. [Ref. 8]

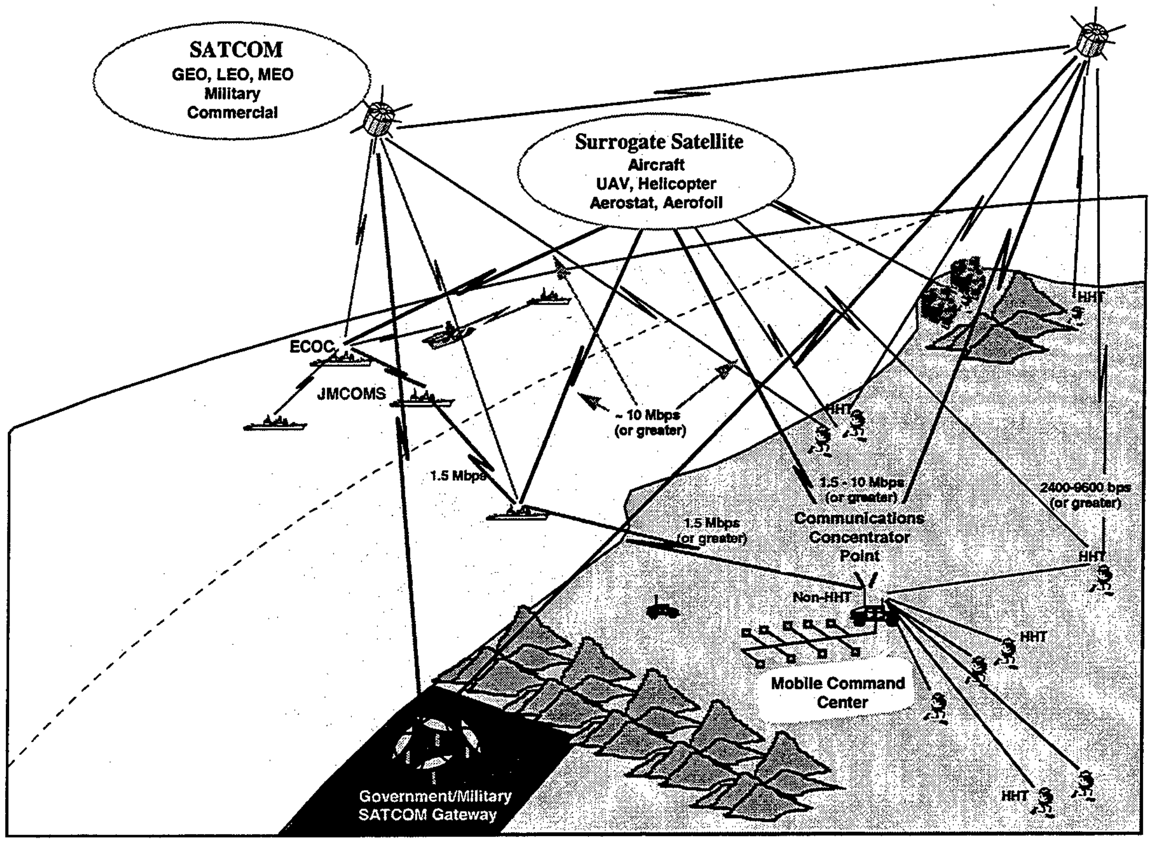

Figure 2. ELB Notional Communication Architecture. [Ref. 8]

The traffic loads for the narrow-band system depends upon the military mission, phase of operation, and command structure chosen for the operation (i.e., hierarchical command or "flattened" structure). There has been no definitive amount of information messages exchanged but efforts have been conducted on probable traffic loading requirements on the narrow-band system.

The Hunter Warrior Exercise provided the first estimate of information exchange requirements. The data requirements from this experiment for each narrow-

band system were one 256 bit position report every 5 minutes and one 512 bit message every 30 minutes to the ECOC. During fire fights, 10% of the radios may be sending calls for fire once per minute for 15 minutes average duration. [Ref. 8] These messages should be received and acknowledged by the ECOC within 10 seconds from time of sending. Information from the ECOC to narrow-band units will be one 2000-bit sitmap update every 15 minutes, One 512 bit message every 15 minutes, and one 10,000 bit free text operation order every 6 hours. A multicast capability that can be organized by geographic location, command structure, or force element is required.

The second estimate is based on a simulation analysis (see Tables 1 and 2) that explored the use of an airborne relay to support amphibious operations. This simulation used two MEU's for the assault and 11 Navy ships but no Army activity. The list below identifies the message type, source and destination, approximate frequency of transmission, and message in bits. To facilitate reading Tables 1and 2, a acronym/abbreviation list is provided in Table 3.

Message Type	Connectivity	Periodicity	Message size (bits)
Observer Status	Spot TM to SACC	every 15 min	150
	SACC to JTF Node	every 15 min	300
Observer Position Report	SACC to JTF Node	every 15 min	1400
Position Report	Spot TM to SACC	every 15 min	700
Spot Report	Spot TM to SACC	every 15 min	1000
Shot-at-Report	Spot TM to SACC	every 15 min	100
MSG to Observer	Shooter - Spot TM	every 15 min	1250
Subsequent Adjustment	Spot TM - Shooter	every 7 min	750
Observer Notification	Shooter – Spot TM	every 7 min	650
End of Mission	Shooter – Spot TM	every 15 min	1000
	JTF Node – SACC	every 8 min	2000
Target List	SACC – JTF Node	every 15 min	8000
Mine Danger	MCMTA – Assets	every 60 min	5000
Platform Status	Asset – MCMTA	every 60 min	2000
	Asset – Asset	every 60 min	1000
Mine-like Contact	Asset – MCMTA	every 60 min	20000
Mine-like Contact	MCMTA – Asset	once each rpt	20000
	Asset – Asset	once each asset	2000
Mine Report	Asset- MCMTA	every 6 min	2000
Mine Actuation	Asset – Asset	every 20 min	2000
Convoy Schedule	MCMTA - Asset	every 60 min	1000

Table 1. Approximate minimum specification of communication traffic to support the pre-assault phase of a 2 MEU amphibious attack. [Ref. 8]

Message Type	Connectivity	Periodicity	Message Size (bits)
Mine Danger Report	CCO - PCS, SCS, LFSP	every 15 minutes	5000
	PCS – Beach Party	every 15 minutes	5000
	PCS – Boat Group CDR	every 15 minutes	5000
	SCS – all ships	every 15 minutes	5000
	CLF – all nodes	every 15 minutes	5000
	AA Co CDR – all nodes	every 15 minutes	5000
	MA Co CDR – all nodes	every 15 minutes	5000
Threat Warning	CATF – all nodes	every 15 minutes	700
	PCS – Beach Party	every 15 minutes	700
	PCS – Boat Group CDR	every 15 minutes	700
	SCS – all nodes	every 15 minutes	700
	CLF – all nodes	every 15 minutes	700
	AA Co CDR – all nodes	every 15 minutes	700
	MA Co CDR – all nodes	every 15 minutes	700
OPORD Boats	CCO – PCS, SCS, LFSP	every 15 minutes	2000
	PCS – Beach Party	every 15 minutes	2000
	PCS – Boat Group CDR	every 15 minutes	2000
OPORD LCAC's	CCO – SCS, LFSP	every 15 minutes	2000
	SCS – all nodes	every 15 minutes	2000
OPORD MA Co	CLF – AA Co CDR	every 15 minutes	2000
OPORD AA Co	CLF – MA Co CDR	every 15 minutes	2000
OPORD General	CLF – all nodes	every 15 minutes	2000
OPORD	AA Co CDR – all nodes	every 15 minutes	2000
	AA PLT LDR – SQD LDRs	every 15 minutes	2000
	MA Co CDR – all nodes	every 15 minutes	2000
	AA PLT LDR – AAVs	every 15 minutes	2000
REDCON MOPP	CATF – all nodes	every 15 minutes	100
	PCS – Beach Party	every 15 minutes	100
	PCS – Boat Group CDR	every 15 minutes	100
	SCS – all nodes	every 15 minutes	100
	CLF – all nodes	every 15 minutes	100
	AA Co CDR – all nodes	every 15 minutes	100
	MA Co CDR – all nodes	every 15 minutes	100
Boat Position Rept	PCS – CCO	every 15 minutes	150
Boat Group Position	Boat Group CDR – PCS,	every 15 minutes	150
LCAC Position Rept	SCS	every 30 seconds	150
	SCSS – CCO	every 30 seconds	150
	LCAC Group CDR – all	every 15 seconds	150
Position Summary	ships	every 15 seconds	300
	LCAC Group CDR – all	every 15 seconds	600
SITREP	ships	every 60 seconds	1500
	AA Co CDR – CLF	every 60 seconds	1500

	MA Co CDR – CLF	every 15 minutes	1500
	All ground nodes – CATF	every 15 minutes	1500
	Node – node	every 15 minutes	1500
	Nodes – all nodes	every 15 minutes	1500
	Boat Group CDR – PCS, SCS	every 15 minutes	1500
	SCS – CLZ CTL TM	every 15 minutes	1500
	LCAC RGP CDR –	every 15 minutes	1500
	SCS,CLZ CTL TM	every 15 minutes	1500
	CLZ CTL TM – SCS	every 15 minutes	1500
PCS Position Report	All nodes – CLF	every 15 minutes	1500
SCS Position Report	All nodes – AA Co CDR	every 15 minutes	1500
Position Report	AA SQD LDRS – AA PLT CDR	every 30 seconds	150
	All nodes – MA Co CDR	every 60 seconds	600
	AAVs – AA PLT LDR	every 60 seconds	600
Obstacle Report	PCS – all ships	every 60 seconds	600
	SCS – all ships	every 7 minutes	600
Bridge Report	AA Plt LDRs – AA Co CDR	every 15 minutes	1000
	AA SQD LDRs – AA PLT	every 15 minutes	1000
	LDR	every 15 minutes	1000
Land Route Report	AAVs – AA PLT LDR	every 15 minutes	1000
Logistics Report	Spot TM – SACC	every 15 minutes	1000
MEDEVAC Request	CLZ CTL TM – all ships	every 5 minutes	500
Observer Status	MA Co CDR – CLF	every 7 minutes	500
Report	PLT LDR – MA Co CDR	every 15 minutes	1500
Observer Position	AA Co CDR - CLF	every 15 minutes	1000
Report	OLR LDR – AA Co CDR	every 7 minutes	150
Observer Notification	MA Co CDR – CLF	every 7 minutes	300
Report	PLT LDR – MA Co CDR	every 15 minutes	1400
Spot Report	All nodes – TACLOG	every 15 minutes	650
Shot-at-Report	MED TM – TACLOG	every 7 minutes	1000
Call for Fire	Spot TM – SACC	every 15 minutes	100
Fire Adjustment	SACC – JTF nodes	every 15 minutes	1000
MSG to Observer	SACC – JTF nodes	every 2 minutes	750
End of Mission	Shooter – Spot TM	every 7 minutes	1250
Target List	Spot TM – SACC	every 15 minutes	1000
Tactical Air Request	Spot TM – SACC	every 15 minutes	2000
Tactical Air Request			4000
Acceptance			1500
			650

Table 2. Approximate minimum specification of communication traffic to support the assault phase of a 2 MEU amphibious attack. [Ref. 8]

Acronyms	
AA: Airborne Assault	LCAC: Landing Craft, Air Cushion
MA: Mechanized Assault	MCAC: Minesweeping Craft, Air Cushion
AFOE: Assault Follow-On Echelon	LCU: Landing Craft
LCO: LCAC Control Officer	AAV: Amphibious Assault Vehicle
LAV: Light Armored Vehicle	CATF: CDR Amphibious Task Force
CCO: Central Command Officer	CLF: CDR Landing Force
SACC: Supporting Arms Coord. Center	PCS: Primary Control Ship
SCS: Secondary Control Ship	PCO: Primary Control Officer
SCO: Secondary Control Officer	NSFS: Naval Surface Fire Support
MCMTA: Mine Counter Measure Tactical Authority	

Table 3. Table of acronyms and abbreviations for Tables 1 and 2. [Ref. 8]

The fire support architecture developed in this thesis will add more fire support messaging in an attempt to add more stress to the system. The notional operational architecture must be capable of supporting these information exchanges in the appropriate time manner.

E. FIRES AND TARGETING (F&T)

This section on F&T describes the activities and identifies the functions needed for the warfighter to be successful rather than focus on a particular system. Targeting is the process of identifying and selecting enemy targets and matching the appropriate weapon or munitions to capture, destroy, degrade, or neutralize it. The warrior goes through inherent functions when conducting targeting. These functions are deciding, detecting, and delivering.

1. Deciding

The deciding function is on-going. It is the need to specify a prioritized list of targets to be acquired and attacked. This function also lays out preliminary plans for

when and how to attack targets, and develops a preliminary plan for acquiring target information to enable execution decisions to be made. One of the most important features of this function is that it develops guidance for coordination among joint forces and maintains an up-to-date inventory of available weapons. This function, especially the weapon inventory, can be automated and two particular systems are discussed in the following chapter.

2. Detecting

The detect function provides continuing information collection to the decide and deliver functions to insure that they are coordinated. This function can either execute the collection plan and directly control the target sensors (i.e. human or machine) or monitor the collection process and extract necessary data. Regardless, it is responsible for acquiring targets and extracting the necessary information for decision-making and weapon employment. This essential information includes the date time group (DTG) the target is detected, target identification, location, description, and any other data that may be needed by the weapon system that is going to engage the target. [Ref. 9] It is vital that standard message format for disseminating targeting information be used to expedite the decide and deliver processes.

3. Delivering

The deliver function carries out the attack guidance and supports the commander's battle plan. This function uses preplanned guidance and information from the decide function including any scheduled targets or time critical targets. Determining time on target or time of launch, desired effects on targets, weapon/target pairing, number of munitions per target, allocation of targets to weapon-launch platforms, and fire

coordination are results of the deliver function. This function provides both fire schedules and action reports to the decide and detect functions.

F. SUMMARY

ELB seeks to make OMFTS a realistic concept. Using the challenges of OTH communications, bandwidth requirements, and the desired capabilities sought by ONR, this thesis will propose an end user terminal, fire support systems, and a narrow-band communications backbone to improve the F&T functions. This improvement will speed up the "steel-on-target" time, improve distances, and help make OMFTS a reality.

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III. NAVAL SURFACE FIRE SUPPORT

A. PROCEDURES

Amphibious operations are the most complex of all military operations. Fire support coordination procedures between the Navy and Marine Corps require a common understanding for success of the operation. [Ref. 10] The goal is to integrate all naval fires to produce the most effective form of power projection ashore. In amphibious operations, the Commander Amphibious Task Force (CATF) is the overall commander of the operation. The CATF commands all elements of the Amphibious Task Fore (ATF), including the fire support elements. Because these fire support elements are organic to component commanders, command of the fire support elements seldom changes. The CATF's command of landing forces (LF) fire support elements is exercised through the Commander Landing Forces (CLF) as a component commander. The CATF's fire support responsibilities consist of planning, targeting. controlling, coordinating, and monitoring fire support activities. The MAGTF commander is the CLF during Navy/Marine Corps amphibious operations. The CLF has the responsibility for the coordination of LF requests for fire support during all phases of the operation. Requests for air and naval fire support are presented to the CATF for prosecution, the CLF plans and controls artillery for the operation. [Ref. 11]

The CATF establishes a Supporting Arms Coordination Center (SACC) at the ATF level of the amphibious organization. The SACC is the single location on board an amphibious command ship in which all communication facilities reside to provide coordination of fire support for artillery, air and naval fire support. [Ref. 11] The SACC is staffed with personnel from the ATF and representatives from the LF.

Initially, the CATF controls air support, naval fire support and artillery, through the CLF. As the first LF elements reach the shore, the portion of control that relates to the firing of specific missions in support of the LF shifts to those elements. With the commencement of on-call fires, the control of supporting arms in the attack of specific targets becomes a LF responsibility when the target affects the LF. [Ref. 11]

The SACC's role is primarily supervising the execution of a detailed fire support plan. Subordinate units within their own boundaries and with adjacent units accomplish coordination of supporting fires, with SACC assistance when required. Subordinate Fire Support Coordination Centers (FSCCs) do not assume action until after execution of the overall ATF planned fires and after FSCCs are ashore. The SACC makes appropriate coordination to achieve a combined arms effect. The CATF phases the responsibility for appropriate fire support coordination and control to the CLF when LFs are phased ashore and operating effectively. The CLF then coordinates the fires of all supporting arms with troop maneuvers. The SACC assumes a monitoring status, prepared to take control and coordination responsibility if required. [Ref. 11]

B. CONCEPTS

Naval fire support is a combination of all assets afloat used to support forces ashore during the initial phases of amphibious operations. Many documents such as Joint Vision 2010, Forward...From the Sea, OMFTS, and the Navy Operational Concept have attempted to define this subject in order to develop what is called the Naval Fires Concept. Along with these documents other factors have been used to define this concept. These factors include:

- The legacy of current capabilities and procedures.

- New technologies enhancing capabilities.
- National policy concerning implementing new technologies.
- Political-military environment.
- Uncertainty of the littoral environment.
- Employment concepts of ground forces in the littorals. [Ref. 12]

The Naval Fires Concept is focused upon integration of fires instead of coordination of fires. Coordination is the sharing of information among operational units as to the timing and location of fires and maneuvers so as to avoid fratricide and duplication of effort. Whereas, integration is the sharing of information among operating units so as to collaboratively plan and execute a scheme of fires and maneuvers whose effects are reinforcing, and complimentary, and which combine to achieve a mutual objective.

The differences between these concepts is that focusing on the integration of fires allows for improvements in operations regardless of the level of improvements in technology. If technology fails to advance as planned, operations can still be improved using existing systems. However, if technology does keep pace, as envisioned, then integration provides for operational improvements to keep pace with technological improvements. The following concepts use integration of fires for success of the operations.

1. Advanced Expeditionary Fire Support

The warfighting concepts outlined in OMFTS and STOM apply the tenets of maneuver warfare. Greater emphasis must be placed on speed, mobility, firepower, and communications to rapidly exploit enemy weaknesses to achieve decisive results. A sea-

based fire support and command and control (C2) system must be used to the maximum extent possible. This will allow greater freedom of maneuver ashore while also improving force protection. In OMFTS and STOM, these naval expeditionary fires will surprise the enemy and create favorable conditions for landing forces.

The advanced expeditionary fire support system must be flexible, robust, and capable of providing responsive, precise, and all-weather fire support (see Figure 3). This system must combine an array of precision, area, and loitering weapons with greater range, improved accuracy and lethality. Combining precision guided munitions and accurately delivered non-precision weapons will provide an optimal mixture of munitions. Fire support changes over the course of amphibious operations. Initially, commanders seek to shape the battlespace to facilitate STOM without comprising tactical surprise. The fires necessary to shape this battlespace will need to provide long-range, precision fires capable of destroying or neutralizing key enemy capabilities. During STOM, high volume suppressive fires will be vital. Naval surface fires and aviation support will provide most of this support. Once forces are ashore and fighting deep inland, naval, aviation, and ground fires will provide fires in support of objectives. *Executed properly, OMFTS will seek to maximize the use of sea-based fires* (see Figure 4).

Fire support systems consists of three elements: command and control, target acquisition, and weapon systems. C2 gives the commanders the ability to influence action. It allows a means for sharing information, selecting weapons systems to engage targets, and controlling and coordinating fire support. Target acquisition is the

identification, location, and analysis of targets. Weapon systems provide the means for attacking targets.

A single integrated (ground, air, naval, and joint) C2 system must exist for expeditionary fire support to be successful. Maneuver elements, often operating deep inland, require highly responsive fires in support of their maneuvers that will quickly attack enemy targets. This C2 system must permit commanders to direct fires, based on tactical situations, firing systems available, response time, weapons available, and commander's guidance. It must also allow the landing force to request and receive fires any time. Fire support coordination must be streamlined to improve responsiveness. C2, target acquisition, and weapons must be improved to support OMFTS.

Key Capabilities

The advanced expeditionary fire support system must be able to provide:

- A single, integrated command and control system
- Flexibility through aviation, naval surface, and ground-based fire support
- Precision point fires
- Accurate, high-volume fire
- Lethal and non-lethal munitions
- Mobility equal to that of the ground maneuver element
- Sufficient range to protect the force and shape the battlespace
- Responsive support for maneuver and force protection
- Maximum use of seabasing
- Minimization of logistics support requirements.

Figure 3. Advanced Expeditionary Fire Support Key Capabilties. [Ref. 5]

The challenge of OMFTS and STOM is to provide continuous, responsive fire support to rapidly maneuvering forces. Fire support for these new warfighting concepts support requires an over-the-horizon, high capacity communications architecture. These

communications must be robust, flexible, and connected to a sea-base for effective naval surface fire support. The C2 system must provide commanders and firing agencies a shared tactical picture and the ability to use naval fires to instantly influence tactical scenarios. The ability to process fire requests and engage targets rapidly is crucial. "Reducing target engagement time, especially time of flight for naval surface fires, is critical to supporting the landing force because seabased systems will provide the majority of fires during the initial phases of the operation." [Ref. 5]

OMFTS from a Fire Support Perspective

- A single, integrated, seabased command and control system will provide a common, real-time battlefield picture to commanders and fire support elements, links to target acquisition and intelligence systems, and coordination and control for aviation, naval surface and ground-based fires.
- All fire support systems will be sustained primarily from the sea.
- Fires will both enable and exploit maneuver.
- Fire support will be capable of providing a range of effects appropriate to the situation, including non-lethal fires.
- Complementary aviation, naval surface, and ground-based fire support systems will provide flexible, reliable, and synergistic fire support.
- Naval surface fire support will provide long-range, accurate fires to shape the battlespace and support the maneuver force.
- Aviation fires will support both the close and the deep battle. Naval aviation will be capable of operating ashore from expeditionary airfields when advantageous.
- Ground-based fires will provide mobile, responsive, all-weather support. They will directly support ground operations and facilitate aviation and naval surface fires, for example, by suppressing enemy air or antiship defenses to enable the delivery of friendly aviation and naval surface fires.

Figure 4. Advance Expeditionary Fire Support Perspective. [Ref. 5]

These improvements in the key capabilities of an amphibious expeditionary fire support system will enable Marine Air Ground Task Force (MAGTF) commanders to

generate overwhelming combat power, tempo, and momentum. This evolution in naval fire support, whether used in STOM or other expeditionary operations, will permit the MAGTF to achieve decisive actions in OMFTS.

2. Ring of Fire

The Ring of Fire (ROF) concept is a method of making naval fire support successful. ROF is described as a local area network comprising a joint fire control network and a joint planning network. Each ship in the ring will have the ability to launch land-attack weapons from other ships in the ring remotely. A ship that is closest to the fight can concentrate on protecting itself and any other supported forces, while land-attack weapons can be launched remotely by a more distant ship. Automating these decisions will expedite the process of passing fire missions from sensor to shooter, eliminating errors associated with voice tasking and reducing the time from ordering missions to ordnance on target. Seven functions are necessary for ROF to successfully coordinate naval fire support:

- Ability to launch land-attack ordnance remotely from any weapons platform.
- Auto-force inventory.
- Ability to apportion ordnance to warfare commanders.
- Auto-pairing of ordnance to targets.
- Common information sharing by all providers and users.
- Automated and integrated deconfliction tools.
- Ability for each land-attack fire control to be the master or decision maker station. [Ref. 13]

C. FIRE SUPPORT SYSTEMS

The joint littoral operations force of 2010 may be an entirely sea-based force, or it may be partially sea-based and partially shore-based. If the latter, the preponderance of forces and headquarters may be at sea or they may be ashore. Alternatively the headquarters may be one place and the preponderance of forces another. A robust C4ISR system will allow for geographic separation of commanders and virtual collocation. The naval component of the force may be conducting the initial operations, or it may be joining operations in progress – bringing massed firepower of carriers, cruisers, destroyers, and submarines to the support for forces ashore.

The role of naval fires in the future will become more complex, and we must find a way to plan for, adapt to, and overcome these complexities. Several key capabilities are required to maximize the role of naval fires in the littoral regions, two of which are related to the focus of this thesis.

A naval fire support C4I system that is automated, reliable, interoperable, and has OTH capabilities is essential. Such systems must allow ground units deep inland as well as those in valleys close to the coast continuous access to the fires integration center and a shared operational picture. They must allow integration of naval fires with joint fires when the Joint Force Commander is ashore. They must allow virtual staffing for the engagement commander by providing real time access to distributed expertise and data bases for planning as well execution. Embedded planning and execution tools that interface directly and efficiently with databases must be established. While highly centralized for planning, the C4I system must allow for both centralized and

decentralized execution to avoid single node vulnerability to attack or failure. The following naval fire support systems provide the aforementioned capabilities.

1. Land Attack Warfare System (LAWS)

LAWS is a system developed by the U.S. Navy for use in conducting naval fires in support of land operations. It is designed to fully automate the targeting, weaponry and information flow of fire support from naval forces afloat to land forces ashore. It is a networked, near real-time system that displays all pertinent information such as friendly unit positions and weapons platform availability, location, and status. It is capable of supporting both reactive targeting (rapid firing in support of targets that suddenly emerge, such as trucks, tanks, troops, etc…) and deliberate targeting (preplanned targets such as SAM sites, bridges, enemy C2 nodes).

LAWS is a PC based system operating in a Windows NT environment (see Figure 5). LAWS uses two standard monitors for increased information display (vice a single display). A standard keyboard and mouse are used for operator input and software manipulation. The system is networked over a standard Local Area network (LAN). All this is important when it comes to setting up the system. There are no special training requirements for setting up LAWS. Any computer specialist familiar with PC's and LAN's will be able to setup and troubleshoot the system. [Ref. 14] All this equipment is COTS (Commercial off the Shelf).

LAWS displays map data of a particular operating region using standard Defense Mapping Agency digital data maps, which is becoming the standard way of loading maps into most tactical data systems. All maps are stored on CD-ROM's, which reduces

storage needs. LAWS supports multiple types of map datum which is significant since many areas of the world are mapped with different datum.

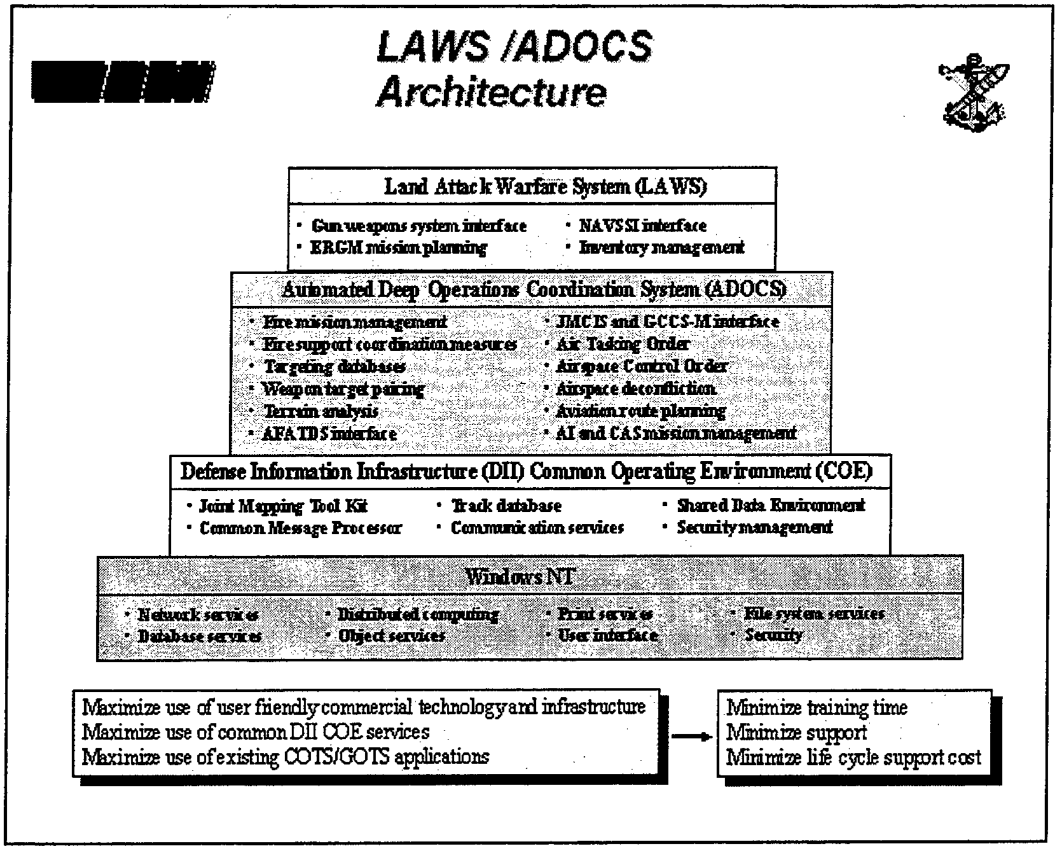

Figure 5. LAWS Architecture and Interface. [Ref. 15]

LAWS will display unit location and information from a JMCIS feed, LINK 16, Advanced Field Artillery Tactical Data Systems (AFATDS) and manual inputs. This provides near real time information. The LAWS director can have the operator rapidly display the following information:

- Weapons Available
- Weapons Platform Location
- Weapons Status (ready to fire, reloading, gun jammed, etc..)

- # of munitions remaining for a given ship/platform
- Range and Bearing from shooter to target
- Friendly positions (to avoid fratricide)

All of these windows can be opened simultaneously and provide the LAWS Director with all information needed to plan fire missions. All of this information is on the network and is automatically updated via various communication links.

After fire support request are submitted to the SACC, they will perform the following functions:

1. Determine target location from requestor and, if possible augment this with imagery from various sources.
2. Allow operator/LAWS director to determine optimum weapons platform to engage target.
3. Allow operator/LAWS director to determine optimum munitions based on availability and number of rounds needed.
4. LAWS will display all pertinent data in a fire mission request window for review
5. An operator will then send the fire mission order to the selected weapons platform
6. LAWS terminal on the firing platform will respond when the round has been fired.

2. Advanced Field Artillery Tactical Data System (AFATDS)

AFATDS is a multi-service automated command and control system comprised of mobile, multi-functional nodes providing planning and execution capabilities to fire

support operational facilities and user centers. [Ref.16] This system operates at the Fire Support Element (FSE), Fire Support Coordination Centers (FSCC) of the supported maneuver force, Field Artillery Command Posts (FACP), Fire Direction Centers (FDC), Tactical Air Command Centers (TACC), Direct Air Support Centers (DASC), and onboard ships. These combined operational elements provide an umbrella of automated fire support. AFATDS combines these operational elements into a singular command, control, and communications solution to the complex problem of integrating and controlling fire support assets. It provides the commander with:

- Updated Situational Awareness (see Figure 6).
- Integrated, responsive and reliable fire support.
- Vastly improved flexibility in providing inputs for items such as commander's criteria and priority of fire information.
- A distributed database for all systems, which will insure that they all are operating with the same information.
- Ability to attack the right target, using the right weapon system, with the right munitions. [Ref. 17]

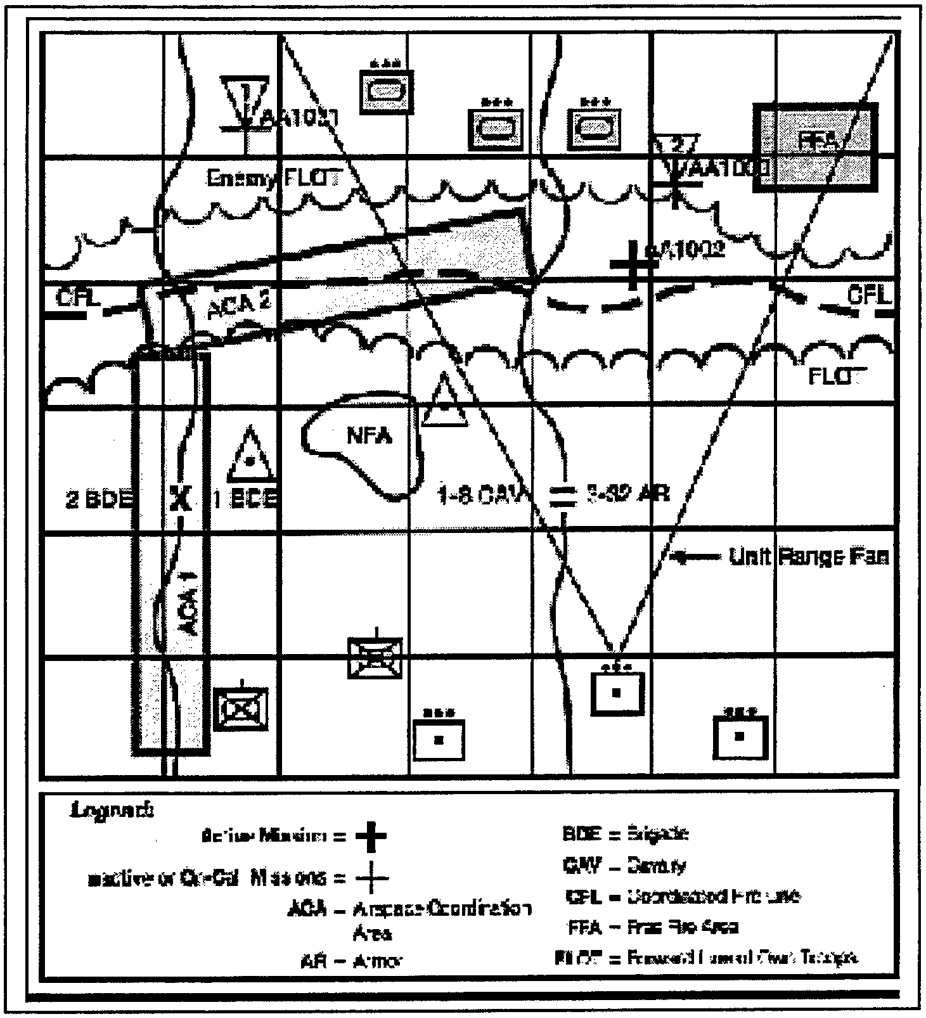

Figure 6. AFATDS Situational Awareness. [Ref. 17]

The major components of AFATDS are the lightweight computer unit (LCU), a 90 MHz Intel Pentium processor, with 32 MB of RAM, a 500 MB removable hard drive, a 10.4" color LCD, and built in SCSI and Ethernet ports (see Figure 7). It is interoperable with the tactical smart modem, and the Tactical Communications Interface Module (TCIM). This allows the system continuous communications with all echelons via electronic mail and data sharing tools. Built with an open system, nonproprietary

architecture, the LCU has the capability to run applications under UNIX, MSDOS, or Windows. Standard software includes MSDOS, Microsoft Windows, and Century modem communications software. The TCIMs provide a powerful interface for computer workstations employed by joint and allied military services. TCIMs allow for data transfer to unique military tactical devices used on the emerging digital battlefield.

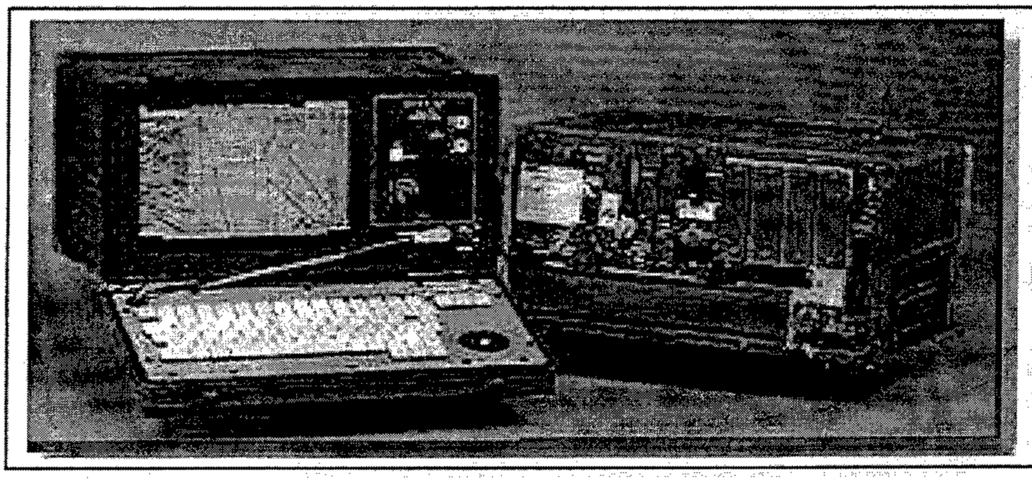

Figure 7. AFATDS. [Ref. 17]

Designed for rugged, on the move operations, TCIMs support horizontal and vertical interoperability for joint and coalition operations. The TCIM not only supports joint systems like JTIDS at rates up to 2 million bps, but also field wire at rates of 512kbps. Combined with the LCU, this system can interoperate with many forms of communications on the battlefield. The software is DISA DII-COE compliant. The TCIM works with over 37 types of joint service communications equipment. It meets current and evolving interface and protocol standards. Man portable and vehicle mounted, the TCIM is a front-end communications processor that supports joint tactical communications for a variety of commercial and military host computers. AFATDS

meets existing field artillery tactical data systems standard message formats and protocols. It is capable of interoperating with joint services using Joint Variable Message Formats (JVMF) or the United States Message Text Formats (USMTF).

3. Palm Enhanced Linked Virtual Information System (PalmELVIS)

PalmELVIS is a palmtop client of the Enhanced Linked Virtual Information System (ELVIS) II Global Command and Control System (GCCS) Common Operational Picture (COP). PalmELVIS provides a palm-sized view of the COP. [Ref . 18] It runs on a Palm Pilot III, made by 3COM, which is the thinnest thin client, rugged and versatile, and simple yet powerful. It uses reliable TCP/IP addressing and supports both continuous and discontinuous communications. PalmELVIS provides a COP view that displays maps and tracks from GCCS while also providing track updates to GCCS via a Global Positioning System (GPS) interface. This small unit also includes the most important aspect for this thesis, which is the ability to send call-for-fire messages (see Figure 8) and operational notes (OPNOTES). PalmELVIS includes simple decision aids that allow for interrogation for amplifying track data, compute range and bearing, and support the use of imagery and scanned maps as background.

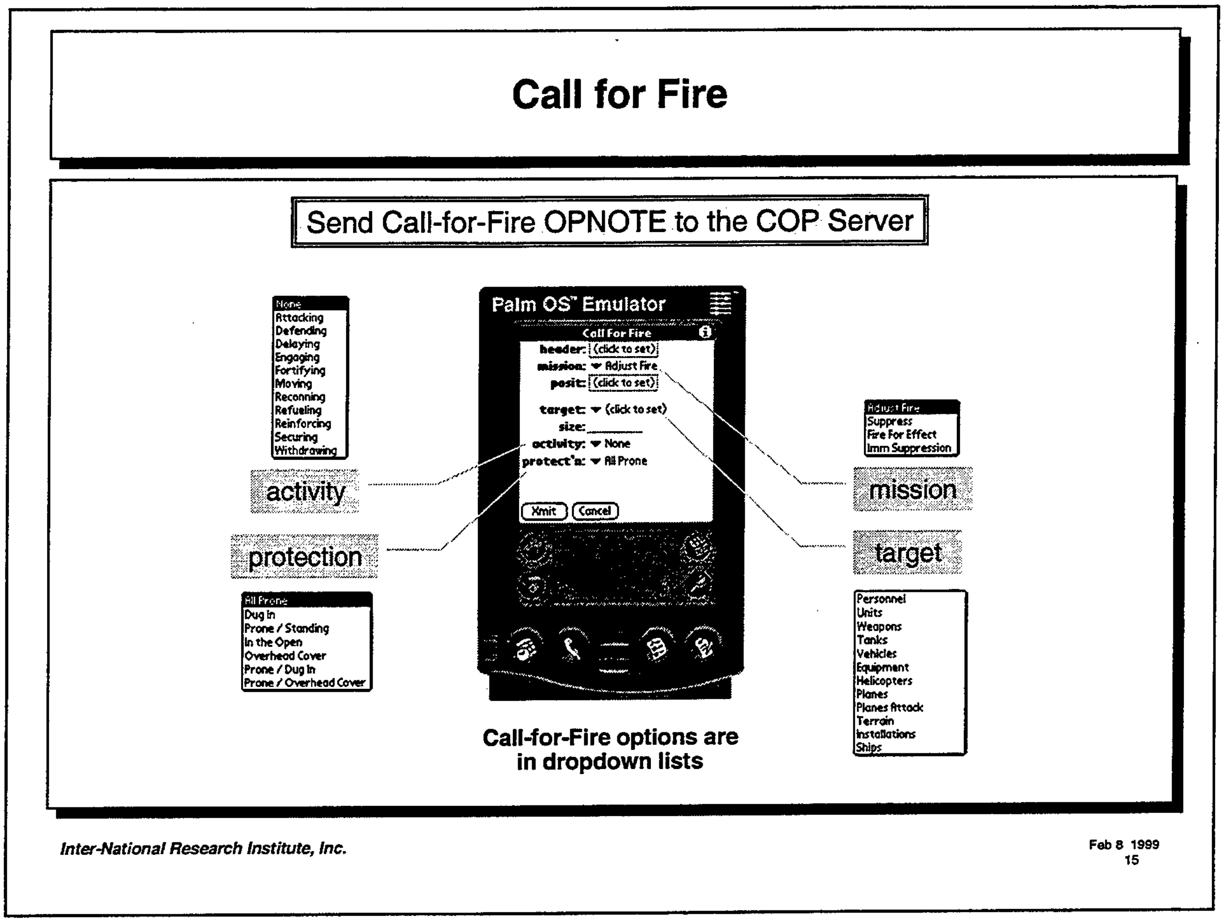

Figure 8. PalmELVIS Call-for-Fire Screen. [Ref. 19]

PalmELVIS connects to an ELVIS II server via TCP/IP, a LAN, or dial-up. ELVIS II is the server that passes information between PalmELVIS and GCCS. ELVIS II is Defense Information Infrastructure (DII) Common Operating Environment (COE) level five compliant. It is available with GCCS version 3.02 and runs on a GCCS workstation. The server interfaces with DII COE for maps, tracks, overlays, ATO, and other information and supports group collaboration. [Ref. 19]

PalmELVIS permits viewing of a portion of the GCCS "tactical picture" in a very small box (see Figure 9). The basic meaning of "tactical picture" is a view of friendly and enemy units (ships, vehicles, groups of people, etc...) shown on a map of some sort.

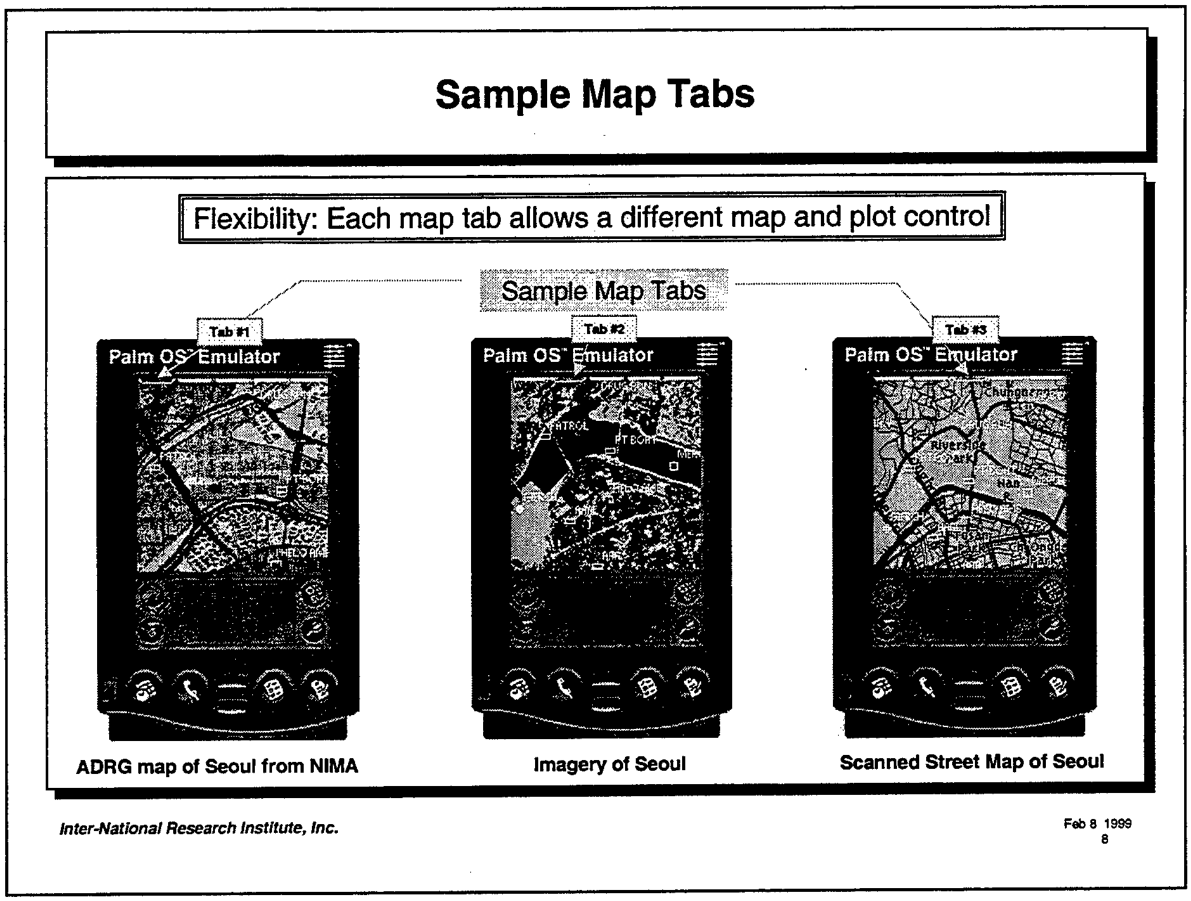

Figure 9. PalmELVIS Mapping. [Ref. 19]

Marines can use PalmELVIS in the field to view the Common Operational Picture near real time on a digitized map screen. It provides a way to see and interact with the COP without carrying larger laptops thus improving Marines situational awareness. Connected into the fire support network, PalmELVIS achieves the desired capabilities and characteristics that the Marine Corps and ONR seek for use in the ELB ACTD '01.

4. Systems Interoperability

LAWS, AFATDS, and PalmELVIS can pass information and more importantly fire support messages between them because of their DII COE compliance. By using the JVMF and the USMTF, these systems can pass and process call-for-fire messages. These systems are also GCCS compliant and can improve each other's situational awareness by exchanging position reporting and status updates. LAWS and AFATDS interoperability has been demonstrated in numerous Fleet Battle Experiments (FBE).

D. BATTLE EXPERIMENTS

1. Fleet Battle Experiments

The Fleet Battle Experiments are a series of experiments directed by the Chief of Naval Operations (CNO) to explore and employ emerging systems and technologies and develop new concepts in accordance with Joint Vision 2010. Although many concepts and technologies were tested, the following discussion is limited to those lessons learned pertaining to this thesis.

a. Fleet Battle Experiment "Alpha" (FEB-A)

FBE-A used a sea-based Special Purpose Marine Air-Ground Task Force (SPMAGTF) employing advanced technology and conducting dispersed operations. The Maritime Battle Center, sponsors of the FBEs, wanted to demonstrate sea-based command and control of a SPMAGTF engaged in OMFTS. They sought to examine command, control, communications, and computers, intelligence, surveillance, and reconnaissance (C4ISR) capabilities and requirements for a sea-based Joint Task Force Commander. The Battle Center evaluated advanced naval surface fire support employing

the arsenal ship and the Naval Surface Fire Support Weapons Control System-Prototype (NWCS-P).

FBE-A successfully demonstrated the "Ring of Fire (ROF)" concept to allocate and coordinate calls for fire in a rapid efficient fashion. The ROF concept demonstrated the capability of a group of firing platforms, acting on a single network, to quickly answer calls for fire. Having immediate access to the status of weapons loadouts on all of the firing platforms was a major benefit of the ROF. This superb concept was of great value and follow-on studies were conducted in the succeeding FBEs. FBE-A demonstrated the sensor-to-shooter concept using the Joint Surveillance Targeting Attack Radar System (JSTARS) and the NWCS ROF concept to transmit target information directly to weapons platforms. [Ref. 20]

b. Fleet Battle Experiment "Bravo" (FBE-B)

FBE-B focused on two specific areas of experimentation: the joint fires coordination process ROF and the JTF targeting process for GPS guided munitions including supporting C4ISR architecture. For FBE-B, the ROF concept was defined as a joint distributive fires network which enables the JTF commander to plan and execute fires in the Joint Operations Area (JOA). The Ring of Fire networked artillery, naval surface fires, close air support, and deep strike land attack employing a variety of weapons. The Navy's Land Attack Warfare Systems (LAWS) was used as the core of the ROF.

FBE-B's Ring of Fire effectively executed joint fire missions. Also, it successfully demonstrated that the ROF "battle" LAN concept was scaleable to the tactical situation, could apply a distributed arsenal of weapons to targets, and respond to

high rates of digital calls for fire. LAWS performed well in a benign environment. FBE-B demonstrated that LAWS operators can successfully service targets when stimulated. The experiment exposed that weapons-target pairing was rudimentary, based primarily on time of flight, without regard for priority, protocol, or precise weaponry. FBE-B did prove that LAWS was inherently flexible for incorporating advanced weapons. LAWS demonstrated a robust automated database for weapons and inventories, especially advanced weapons. Finally, the experiment demonstrated that AFATDS and J-STARS integration is of particular value in the littoral. AFATDS and J-STARS integration enhanced joint interoperability testing. [Ref. 21]

c. Fleet Battle Experiment "Charlie" (FBE-C)

FBE-C examined network-centric warfare in the littoral with a focus on two conceptual warfare themes:

- Area Air Defense Commander
- Ring of Fires (Naval Fires)

The experiment was divided into two phases. Phase I examined the planning and execution of the Area Air Defense Commander's (AADC) for theatre air and missile defense in the JOA. Phase II continued experimentation and maturation of the Ring of Fire concept conceived and developed in FBE-A&B.

The FBE-C ROF networked naval surface fires, close air support, and deep strike land attack employing a variety of weapons in a simulated environment. LAWS once again served as the core of the ROF. Seven LAWS terminals were used in the Joint Fires Cell. Building on previous ROF experiments, additional ROF experimental factors and LAWS functionalities were added to those of FBE-B. These

factors were: greater use and integration of CAS; more robust and better integrated LAWS deconfliction tools; more sophisticated target prioritization criteria with regards to time latency; improved weapon-target pairing which considered weapons inventory's as well as weapons effects and time to engage; and automatic check fire for No Fire Areas (NFAs).

The experiment re-substantiated that the ROF concept for executing joint fire missions and LAWS performance was outstanding. FBE-C also demonstrated that the ROF "battle" Wide Area Network (WAN) concept is easily adaptable to a notional Joint Fires Cell. It also proved that ROF can manage the near battle inside the Fire Support Coordination Lines (FSCLs) as well as deep battles beyond the FSCL and the ROF can manage resources in accordance with a JTF Commander's guidance and firing matrix. Finally, FBE-C showed that follow-on ROF should include artillery experiments and continue to work on AFATDS-LAWS interoperability. [Ref. 22]

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IV. SATELLITE CONSTELLATIONS

A. INTRODUCTION

Information is becoming increasingly essential to all those things associated with quality of life: economic opportunity, education, health care, and public services. Yet, most people in the world today do not have access to the most basic telephone service. To cite just one statistic, more than half the world's population lives more than two hours' travel time from the nearest telephone. The high cost of wireline infrastructure has often kept telecommunications services from remote areas. Vast regions of the developing world are completely without telephone service. India has 900 million people but only about seven million telephone lines, virtually all of them clustered in a few large cities. Where basic telephone service is available, the networks over which it is provided consist of 100-year-old technology – analog signals on copper wire – that for the overwhelming part will never be upgraded to the digital, broadband capability required for the advanced network connections that have come to be known as the information superhighway. Using the most optimistic estimates of costs per mile, there is little possibility that any developing nation will be able to fund the engineering effort that created the existing terrestrial wireline networks of Europe and North America. Even in developed countries, there is a risk that rural areas and populations will be denied access to the powerful digital technologies that are changing the world. [Ref. 24] Three low earth orbit (LEO) based systems, Iridium, Teledesic, and Globalstar, were formed with the objective of creating a means of providing affordable access to advanced network connections to all parts of the world that will never receive such advanced capabilities through existing technologies. [Ref. 25]

These LEO systems each focused on a different service segment and a different portion of the radio frequency spectrum. The best way of distinguishing between these three LEO system types is by reference to their corresponding terrestrial (land-line) services:

• "Little LEOs," like OrbComm, are the satellite equivalent of paging. They operate below 1 GHz, and provide simple store-and-forward messaging. These systems offer low data rates but can provide valuable services in a wide range of settings, such as remote monitoring and vehicle tracking.

• "Big LEOs" like Iridium, Globalstar and ICO, have received the most attention. They are the satellite equivalent of cellular phone service, and operate between 1 and 3 GHz.

• Teledesic is the first proposed "broadband LEO." It will provide the satellite equivalent to optical fiber. Because it will operate in the Ka band, essentially line-of-sight from the user terminal to the satellite is required, which makes it more appropriate for fixed applications, or mobile applications like maritime and aviation use, where line-of-sight is not an issue. It will provide the advanced, digital broadband network connections to all those parts of the world that are not likely to get those capabilities through wireline means. [Ref. 26]

B. IRIDIUM

Iridium, a "Big LEO", will be the first major constellation to actually provide service to customers. Iridium services will become the ultimate solution to wireless communications and worldwide connectivity. The Iridium system (see Figure 10) promises to offer access to dial tone virtually anywhere on earth. By the year-end 2000,

the number of cellular subscribers worldwide is expected to reach 295 million, along with 160 million paging subscribers. Iridium, Inc. anticipates serving 650,000 voice and 350,000 paging subscribers worldwide in 2000. For undeveloped areas where telephone systems infrastructure costs have been prohibitive, the Iridium system provides governments and telecommunications providers with either an economical alternative or an interim service.

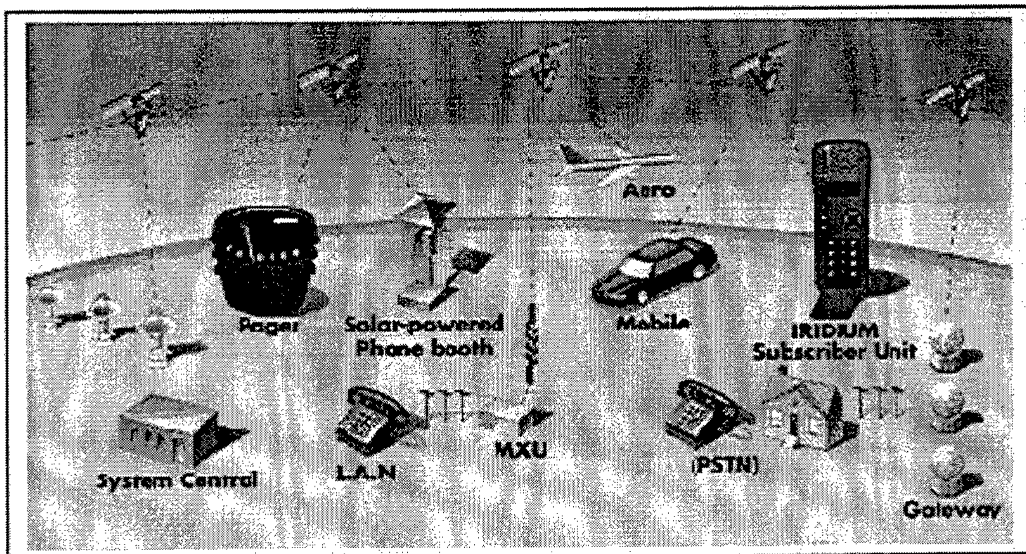

Figure 10. Iridium Architecture. [Ref. 26]

Based in Washington D.C., Iridium is a satellite-based, wireless personal communications network designed to permit any type of telephone transmission to reach its destination anywhere on earth. The Iridium system was conceived in 1987 by engineers at Motorola's Satellite Communications Division. With the goal of providing truly global coverage, engineers determined that the system would require a constellation of low earth orbiting (LEO) satellites. The satellites would be relatively small and simply constructed so they could be built, launched and replaced economically.

Market analyses conducted by Motorola determined the requirements for system capacity and financing. A strong potential market was identified for a system that would provide high quality service at reasonable rates. [Ref. 27]

Iridium will bring a new dimension of capability to the commercial, rural and mobile areas by providing universal, portable service. Subscribers will use wireless, pocket-sized Iridium telephones, transmitting through digital facilities, to communicate with any other telephone in the world. Unlike regular telecommunication networks, the 66 satellite system will track the location of the telephone handset, providing global transmission even if the subscriber's location is unknown. In areas where cellular service is available, the dual mode phone will provide the option of transmitting a call through the cellular system. For the first time in history, individuals will soon have the ability to use one telephone to make or receive calls from anywhere on the planet.

Iridium is an international consortium of leading telecommunications and industrial companies that owns the satellite constellation and is responsible for providing the funding for the construction and implementation of the Iridium system. In addition, this company is responsible for network operations, standards and operating practices, and corporate relations.

1. Satellite Characteristics

Iridium's network of satellites will orbit the earth at a height of 413 nautical miles, ensuring that every point on the earth's surface is in continuous line of sight with one of the satellites. The satellites will be deployed in six circular polar orbits, with 11 satellites per plane. Each satellite in the constellation is connected by radio transmission to four others making it possible to hand off calls between satellites in the same or

adjacent orbiting planes. The satellites (see Figure 11) are lightweight, approximately 725 kilograms and have an expected lifespan of five to six years. They are considered "smart" because they can switch and route calls in space. Each satellite antenna pattern will project 48 cells onto the earth's surface. Each cell will provide communications coverage for an area of the earth's surface roughly 350 nautical miles in diameter; people will communicate with the satellites using equipment operating at frequencies of 1.5/1.6 gigahertz, just above land-based cellular radiotelephones. In addition to voice, the digital system can transmit data at a rate of 2400 baud. [Ref. 27]

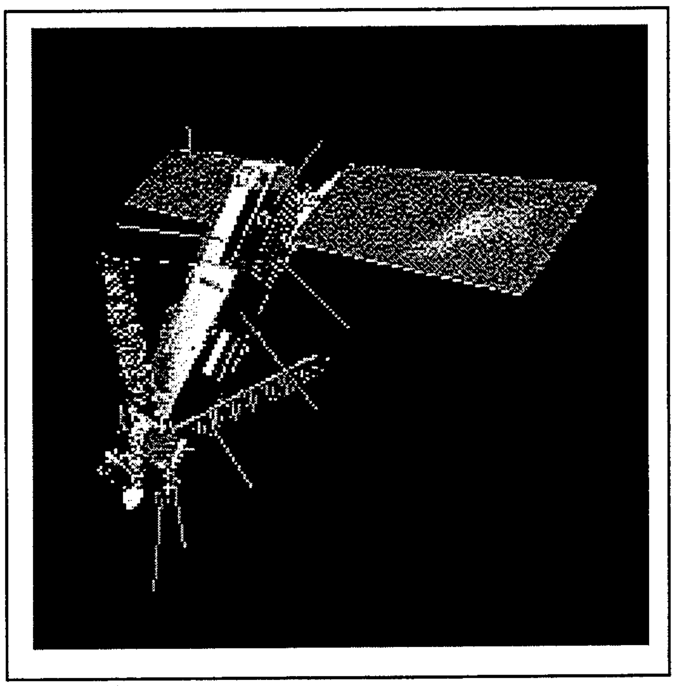

Figure 11. Iridium Satellite. [Ref. 26]

2. Iridium Gateways

Another key component of the system will be a network of "gateway" surface facilities in various countries that will link Iridium with the public switched telephone network (PSTN). This makes communications between Iridium telephones and any other telephone in the world possible. These gateways will store customer billing information and will constantly keep track of each user's location. An Iridium system control facility will maintain the satellite network and the overall operation of the system. [Ref. 29]

3. Communication Links

The Iridium system will employ a combination of Frequency Division Multiple Access and Time Division Multiple Access (FDMA/TDMA) signal multiplexing to make the most efficient use of limited spectrum. The following is a list of the communication links the Iridium system will use:

•Mobile L-Band Service links	
Downlinks	1610-1626.5 MHz, L-Band
Uplinks	1610-1626.5 MHz
•Intersatellite Links	23.18-23.38 GHz, Ka-Band
•Gateway/TT&C Links	
Downlinks	19.4-19.6 GHz, Ka-Band
Uplinks	29.1-29.3 GHz, Ka-Band

4. Subscriber Units

The Subscriber units (see Figure 12) are similar to Motorola's original cellular radiotelephones and will offer additional features such as latitude, longitude, altitude and Greenwich Mean Time. In addition to the lightweight portables, Iridium subscriber units will be available as mobiles or small fixed units. The Iridium system will support millions of users worldwide, with a total capacity more than 10 times greater than current

geosynchronous satellite systems. The following is a brief description of each type of subscriber unit available:

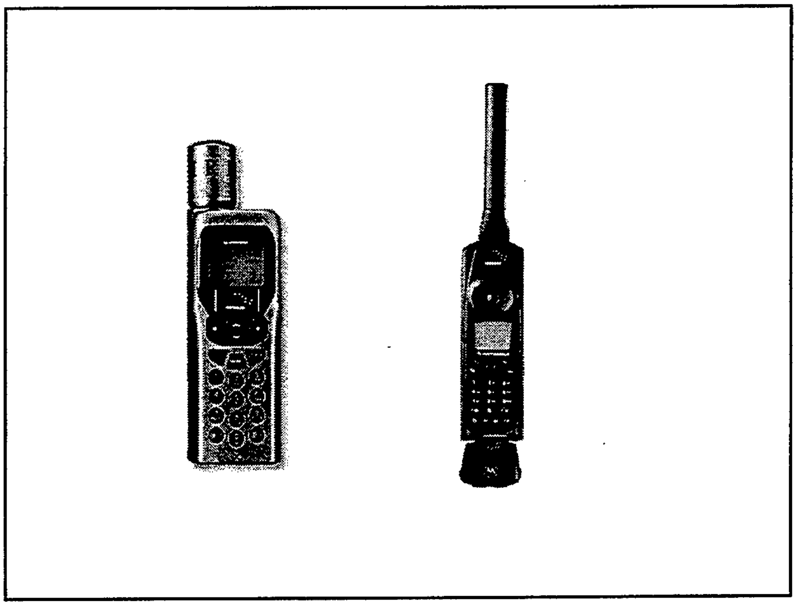

Figure 12. Iridium Subscriber Units. [Ref. 29]

Iridium Handheld Telephone

- Dual-mode: satellite and terrestrial wireless compatible
- Digital voice: includes data port for transmitting facsimile and computer files
- Transmission rates: voice (Full-duplex, 2.4 Kilobits/sec); data (2400 baud)
- Modulation: QPSK with Frequency Division/Time Division Multiple Access (FDMA/TDMA)
- Similar design to Motorola cellular phone
- Uses digital facilities for maximum clarity and signal quality
- Batteries: 1 hour talk time and 24 hours of standby time

Iridium Pager

- Capable of receiving 66 character alphanumeric messages
- Message display available in international character set
- Off the shelf disposable battery: one month lifetime

5. Iridium Launch Services

Launching upwards of 66 space vehicles to build a satellite constellation requires more than one launch vehicle. Motorola's Satellite Communications Group chose to distribute its launch program among three vehicles to ensure continuing access to space and reduce the risk of delay. The Iridium satellite launch vehicles are among the world's most proven and reliable, but their different physical sizes, payload capabilities, flight characteristics, and interfaces preclude consideration of a single system for deploying the Iridium satellites into low Earth orbit. [Ref. 26]

a. The Proton

A state-owned aerospace engineering and manufacturing company in the Russian Federation, Khrunichev State Research and Production Space Center did provide launch services using three Proton rockets to loft 21 of the 66 operating satellites. The Proton launch vehicle is the largest of the three rockets that the Iridium system will use to deploy its constellation. It has the capacity to place seven Iridium satellites directly into a circular transfer orbit at 512 km (317 miles), where the satellites will be deployed from the dispenser. Proton launches are scheduled to take place at the Baikonur launch facility in Kazakhstan. [Ref. 27]

b. The Delta II

The first launch of Iridium satellites, was from Vandenberg Air Force Base in California, USA aboard a Delta II rocket built by McDonnell Douglas. The rocket carried five Iridium satellites in the first launch and carried five satellites in each of the eight scheduled subsequent launches, eventually deploying 40 of the 66 operational satellites. In addition to a new satellite dispenser, capable of deploying 5 satellites

simultaneously, the Delta also features a new composite payload fairing. In the past all of McDonnell Douglas' fairings had been more of a classical aerospace structure of aluminum, skins, and ribs. However, McDonnell Douglas saw an opportunity with multiple launches to develop a new composite fairing that increases performance for the rocket and reduces both the manufacturing costs and the cycle time producing the hardware. [Ref. 27]

c. The Long March 2C/SD

The Long March 2C/SD rocket, built by China Great Wall Industry Corporation, launches Iridium satellites two at a time into orbit from the Taiyuan Satellite Launch Center in China. The modified Long March 2C rocket with a Smart Dispenser (hence Long March-2C/SD) was built specifically for the Iridium system. Launch rehearsals, known as Pathfinder exercises, were conducted in 1996. A Long March 2C rocket had been previously transported from the China Academy of Launch Technology in Beijing to the Taiyuan Satellite Launch Center, which is located 400 miles southwest. The Pathfinder exercises included dummy fueling, mating onto the dispenser, and interface checks with the launch vehicle. [Ref. 27]

C. TELEDESIC

The Teledesic Network (see Figure 14) is a high-capacity broadband network that combines the global coverage and low latency of a low-Earth-orbit constellation of satellites, the flexibility and robustness of the Internet, and "fiber-like" quality of service. Essentially an "Internet-in-the Sky," the Teledesic Network will be the first satellite system that can handle any kind of communication, from voice calls to Internet browsing to video and interactive multimedia. The Teledesic Network can serve as the access link

between a user and a gateway into a terrestrial network, or as the means to link users or networks together. Covering nearly 100 percent of the Earth's population and 95 percent of the landmass, the Teledesic Network is designed to support millions of simultaneous users. [Ref. 28]

The Teledesic Corporation was founded in 1990 and is headquartered in Kirkland, Washington. Principal shareholders are its Chairman and CEO, Craig McCaw, the founder of McCaw Cellular Communications which was the world's largest cellular communications company before its 1994 merger with AT&T, and William H. Gates III, the co-founder, Chairman and CEO of Microsoft Corporation, the world's largest computer software company. [Ref. 29] At the 1995 World Radio Conference, Teledesic received support to form a new international satellite service designation for the frequencies necessary to accommodate the Teledesic Network. The lowest frequency band with sufficient spectrum to meet Teledesic's wideband service, quality and capacity objectives is the Ka-band. The terminal-satellite communication links operate within the portion of the Ka frequency band that has been identified internationally for non-geostationary fixed service. Teledesic was also successful in obtaining a similar designation from the US Federal Communication Commission (FCC). In March 1997, the FCC licensed Teledesic to build, launch, and operate the Teledesic Network. [Ref. 30]

In April 1997, Teledesic announced that The Boeing Company would become an equity partner in Teledesic and serve as the prime contractor for the company's global, broadband "Internet-in-the-Sky." Boeing would invest up to $100 million for 10 percent of the current ownership of Teledesic. Teledesic's credibility was further boosted by a

new plan, presented by Boeing, to reduce the number of satellites in the network to 288 and place them in a higher orbit than was projected in an original 840 satellite plan. Teledesic plans on drawing on the core competencies of Boeing, which include large-scale systems integration, software development and launch services. [Ref. 31]

A test satellite for the Teledesic system was launched in February 1998. Dubbed the T1, it marks the first successful orbit of a commercial, Ka-band low earth orbit satellite. Teledesic plans to begin launching operational satellites in the year 2002 with service beginning the following year. Initially, Teledesic does not intend to market services directly to end-users. Rather, it will provide an open network for the delivery of such services by others. The Teledesic Network will enable local telephone companies and government authorities in host countries to extend their networks, both in terms of geographical area and in the kinds of services they can offer. Ground-based gateways will enable service providers to offer seamless links to other wireline and wireless networks. [Ref. 32]

The latest major development occurred on May 21, 1998 when Motorola Inc. invested roughly $750 million into Teledesic in return for a 26 percent share in the system, replacing Boeing as the prime contractor. While being replaced as the prime contractor, Boeing remains part of the development partnership of Teledesic. Motorola will combine technical efforts already under way on the Teledesic system with those planned for their proposed Celestri system, which has now been abandoned and its concepts merged into the Teledesic system. Teledesic also plans to draw on its partnership with Matra Marconi Space's expertise in satellite bus manufacturing, which claims to be able to build a Teledesic satellite in an astounding four days. [Ref. 33]

Teledesic's engineering effort builds on previous work done in many advanced commercial and government satellite programs and was assisted by several government laboratories. The Teledesic system utilizes proven technology and experience from many U.S. defense programs, such as the Strategic Defense Initiative (SDI) project "Brilliant Pebbles," which was conceived as a similar orbiting global constellation of 1,000 small, advanced, semi-autonomous, interconnected satellites. Since 1990, Teledesic has drawn on the expertise of the contractors on that and many other programs for input into the early system design activities. [Ref. 30]

Design, construction, and deployment costs of the Teledesic network are estimated at 9 billion dollars. The Teledesic satellites and their associated subsystems will be designed and built in quantities large enough to be mass-produced and tested. In geostationary systems, any single satellite loss or failure is catastrophic to the system. To reduce this contingency to acceptable levels, reliability can be built into the network rather than the individual unit, reducing the complexity and cost of the individual satellites and enabling more streamlined, automated manufacturing processes and associated design enhancements. In its distributed architecture, dynamic routing, and scalability, the Teledesic Network emulates the Internet, while adding the benefits of real-time capability location-insensitive access. [Ref. 34]

1. System Architecture Requirements

To ensure seamless compatibility with terrestrial communication networks, a satellite system must be designed with the same essential characteristics as a fiber optic network. Communications satellite systems are of two general types: geostationary-Earth-orbit (GEO) and non-geostationary, primarily low-Earth-orbit (LEO). GEO satellite

systems orbit at an altitude of 41,164 km above the equator, the only orbit that allows the satellite to maintain a fixed position in relation to Earth. At this height, communications through GEOs (which can travel only as fast as the speed of light) entail a round-trip transmission delay of at least one-half second. This GEO latency is the source of the annoying delay in many intercontinental phone calls, impeding understanding and distorting speech. What can be an inconvenience on voice transmissions, however, can be untenable for real-time applications such as videoconferencing as well as many standard data protocols. This means that GEOs can never provide fiber-like quality needed for some applications, especially the protocols of the Internet. [Ref. 35]

GEO satellite communications systems require changes to terrestrial network standards and protocols to accommodate their inherent high latency. In contrast, Teledesic's objective is to meet current network standards rather than to change them. By using fiber-optic as the guideline for service quality, the Teledesic Network is designed for compatibility with applications that are based on the networking protocols of today and tomorrow. This places stringent requirements on the system design, including low latency, low error rates, high service availability, and flexible, broadband capacity – all characteristics of fiber. The advanced digital broadband networks will be packet-switched networks in which voice, video, and data are all just packets of digitized bits. It is not feasible to separate out applications that can tolerate delay from those that can't. As a result, the network has to be designed for the most demanding application. [Ref. 34]

2. Orbit and Constellation

Teledesic plans to alleviate the known GEO communication problems with a huge LEO satellite constellation. Latency is a critical parameter of communication service quality, particularly for interactive communication and for many standard data protocols. To be compatible with the latency requirements of protocols developed for the terrestrial broadband infrastructure, Teledesic satellites will orbit at low altitude, under 1,400 kilometers. Downlinks will transmit between 18.8 GHz and 19.3 GHz, and uplinks will operate between 28.6 GHz and 29.1 GHz. Communication links at these frequencies are degraded by rain and blocked by obstacles in the line-of-sight. To avoid obstacles and limit the portion of the signal path exposed to rain requires that the satellite serving a terminal be at a high elevation angle above the horizon. The Teledesic constellation guarantees a minimum elevation angle of 40° within its entire service area. [Ref. 34]

The combination of high mask angle and low-Earth-orbit result in a relatively small satellite coverage zone, or footprint, that enables efficient spectrum re-use but requires a large number of satellites to serve the entire Earth. In the initial constellation, the Teledesic Network will consist of 288 operational satellites, divided into 12 planes, each with 24 satellites. The altitudes of satellites in different orbit planes are staggered to eliminate the possibility of collision between satellites in crossing orbits. Once the satellites are aloft they will circle in a polar orbit from north to south. The orbit planes are at a sun-synchronous inclination (approximately 98.2°), which keeps them at a constant relative angle to the sun. [Ref. 28]

3. Space Segment

The Teledesic satellites are complex, employing state-of-the-art technologies such as inter-satellite links, phased array antennas, advanced battery cells, and gallium arsenide integrated circuits. An underlying goal in their design is high volume production and test processes. On orbit, the satellites will operate with a high degree of autonomy, with on-board systems for orbit determination, navigation, and health monitoring. Each satellite monitors its status and periodically sends reports on its vital functions to the Constellation Operations Control Centers (COCC). Exception conditions are reported immediately. The COCC sends commands to the satellite and its subsystems as necessary in response to exception conditions. Figure 13. illustrates the satellite's on orbit configuration. [Ref. 38]

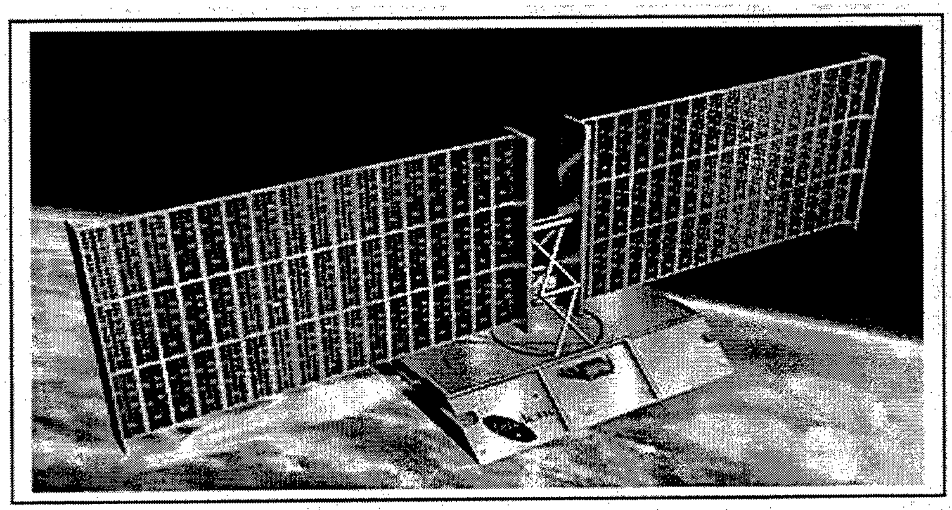

Figure 13. Teledesic Satellite. [Ref. 36]

On-board processing will be accomplished through the command and data handling subsystem (C&DH), consisting of multiple high-speed microprocessors, a high-capacity solid-state random access memory (RAM), a LAN for connection with other bus

components, as well as an engineering diagnostic and trending (EDAT) processor. The rectangular baseplate supports eight pairs of inter-satellite link antennas, three large electronically steered phased-array antenna panels, the two satellite bus structures that house the engineering subsystem components, and propulsion thrusters. A third satellite bus structure will contain the power equipment and additional thrusters. The attitude and orbit determination and control (AODC) subsystem will use acquisition sun sensors to orient the satellite immediately after orbit insertion and inertial measuring units, magnetometers, and precision microwave nadir-pointing information for attitude sensing afterward. Satellite attitude will be maintained in all three axes to within 0.2 degrees via magnetic torque and reaction wheels. The electronic beam steering of the antenna will have an accuracy of 0.1 degree. Stationkeeping and other orbit maneuvers will be performed using redundant low-thrust electric powered thrusters, which have a ΔV budget in excess of 1000 m/s. Thermal control will be semipassive using a combination of thermal blankets and paint for bus elements and phase-change thermal capacitors and heat pipe devices for the payload. Batteries will allow full payload operation during eclipse periods. [Ref. 36]

The estimated on-orbit lifetime of each satellite is 10 years. Degradables and consumables (i.e., solar array, batteries, propellant, etc.) have been sized to exceed the 10 year lifetime. Each satellite carries over twice the propellant needed to insert itself into its orbital position, to overcome any minor atmospheric drag, to reposition itself when required, and to perform a final deorbit maneuver. [Ref. 36]

4. Communications Payload

The communications payload is the heart of the Teledesic satellite and is centered around the fast packet switch (FPS). This switch is responsible for routing data packets to and from the Scanning Beam (SB) subsystem, the GigaLink Satellite Link (GSL) subsystem and the Inter-Satellite Link (ISL) subsystem. The FPS is essentially non-blocking with very low packet delay, and has a throughput in excess of 5 Gbps. Each subsystem consists of an active element phased array antenna for transmitting and receiving signals. For the transmit side, all data packets received from the FPS are encoded and modulated to form an IF signal which is then upconverted and applied to the particular array. The antenna converts RF signals to a free-space propagated waveform with the proper polarization for the Earth-fixed cell or satellite it is serving. The receive side operates in a similar manner but in the opposite direction. The SB subsystem is responsible for scanning the corresponding Earth-fixed cell the satellite is currently serving. As the satellite movement causes a cell to pass out of view of one array and into the view of the next, coverage responsibility is passed from one array to the next. The FPS routes packets addressed to a user terminal within the satellite's coverage zone to the SB antenna currently serving that cell. The GSL subsystem operates similarly to the SB system but serves the ground-based GigaLink terminals in its corresponding cell. The ISL subsystem uses its array to communicate with the eight adjacent satellites in the constellation. All signals are pre-compensated to eliminate the apparent Doppler shift due to the satellite's movement. A frequency reference subsystem provides stable frequency and time reference to the SB, GSL, and ISL subsystems while a computer subsystem provides control information to the FPS and SB, GSL, and ISL subsystems. [Ref. 36]

5. Launch Segment

The Teledesic satellite is specifically designed to take advantage of the economies that result from high volume production and launch. To minimize launch costs and the deployment interval, the satellites are designed to be compatible with over twenty existing international launch systems, and to be stacked so that multiple satellites can be launched on a single vehicle. Teledesic plans to use a combination of existing domestic and international launch vehicles to deploy the initial constellation, including on-orbit spares, over a two-year period. Individual satellites, the constellation as a whole, and the COCCs are designed to operate with a high degree of autonomy. The initial constellation includes a number of active on-orbit spares that can be used to "repair" the network immediately if a satellite is removed from service temporarily or permanently. Routine periodic launches will be used to maintain appropriate levels of spares in each orbit plane. Launch vehicles and satellites that have reached the end of their useful life are deorbited. They disintegrate harmlessly on re-entry, and will not create space debris. [Ref. 28]

6. Ground Segment

The Teledesic ground segment consists of terminals, network GigaLink gateways and network operations and control systems. Terminals are the hub of the Teledesic Network and provide the interface both between the satellite network and the terrestrial end-users and networks. They perform the translation between the Teledesic Network's internal protocols and the standard protocols of the terrestrial world, thus isolating the satellite-based core network from complexity and change. [Ref. 34]

Teledesic terminals communicate directly with the satellite network and support a wide range of data rates. The terminals also interface with a wide range of standard network protocols, including IP, ISDN, ATM, and others. Although optimized for service to fixed-site terminals, the Teledesic Network is able to serve transportable and mobile terminals, such as those for maritime and aviation applications [Ref. 28]. These terminals can use antennas with diameters from 16 cm to 1.8 m as determined by the terminals' maximum transmit channel rate, climatic region, and availability requirements. Their average transmit power will vary from less than 0.01 W to 4.7 W. [Ref. 37] The Teledesic terminals will provide the interconnection points for the Teledesic Network's Constellation Operations Control Centers and Network Operations Control Centers (NOCC). COCCs coordinate initial deployment of the satellites, replenishment of spares, fault diagnosis, repair, and de-orbiting. The autonomous design of Teledesic satellites minimizes the required telemetry, tracking and command communication required from the COCCs. The satellites report exception conditions immediately and periodically send status reports on vital functions to the COCCs. The NOCCs include a variety of distributed network administration and control functions including network databases, feature processors, network management and billing systems. [Ref. 34] GigaLink Terminals provide gateway connections to public networks and to Teledesic support and database systems including NOCCs and COCCs, as well as to privately owned networks and high-rate terminals. A satellite can support up to sixteen GigaLink Terminals within its service area. [Ref. 37]

7. Network Operations

The Teledesic Network (see Figure 14) is a dynamic constellation of a minimum of 288 identical operating satellites. Each satellite functions as a communications node of equal rank and importance that is linked to its eight closest neighbors and independently handles traffic without ground control. The degree of autonomy with which each satellite operates represents a significant advance in space technology. The on-board orbit determination and navigation subsystem developed by Teledesic represents an innovation that significantly advances the state-of-the-art of LEO satellite telecommunications. Each satellite continuously and autonomously determines its own position and attitude, and maintains its position within the constellation by adjusting its attitude and position within the orbit plane. The orbit determination and navigation subsystem employs ranging between satellites and to points on the earth's surface as a reference to determine and maintain the satellite's position. This precision position information is used to select the optimum path for routing packets among the satellites in the constellation. It is also used to steer the phased-array antennas to the Earth-fixed cell grid and to neighboring satellites. In addition, each satellite continuously monitors its own health and analyzes trends to project future problems. The high degree of system autonomy assures network integrity and enhances its efficiency, thereby reducing costs. [Ref. 36]

Teledesic has designed its system using an Earth-fixed cell design to avoid the "hand-off" inefficiencies and service interruption that would result if the small cell pattern swept over the Earth at the velocity of the satellite footprint. Teledesic's proposal represents the first application of this innovative feature for a commercial LEO satellite system. Teledesic cells and their associated communication channel resources are

organized in an Earth-fixed grid. As a satellite passes over the fixed cell, the satellite steers its antenna beams to the fixed cell locations within its coverage area. This allows a terminal to maintain the same channel assignment even though it may be served by several different beams and satellites during a call. This concept maximizes frequency reuse and system capacity and minimizes processing costs and frequency management problems. As a result, Teledesic's system reuses spectrum over 350 times within the United States and over 20,000 times worldwide. This concept also allows Teledesic to contour its service offering to geographical boundaries, which is difficult to accomplish with large cells that move with the satellite. [Ref. 36]

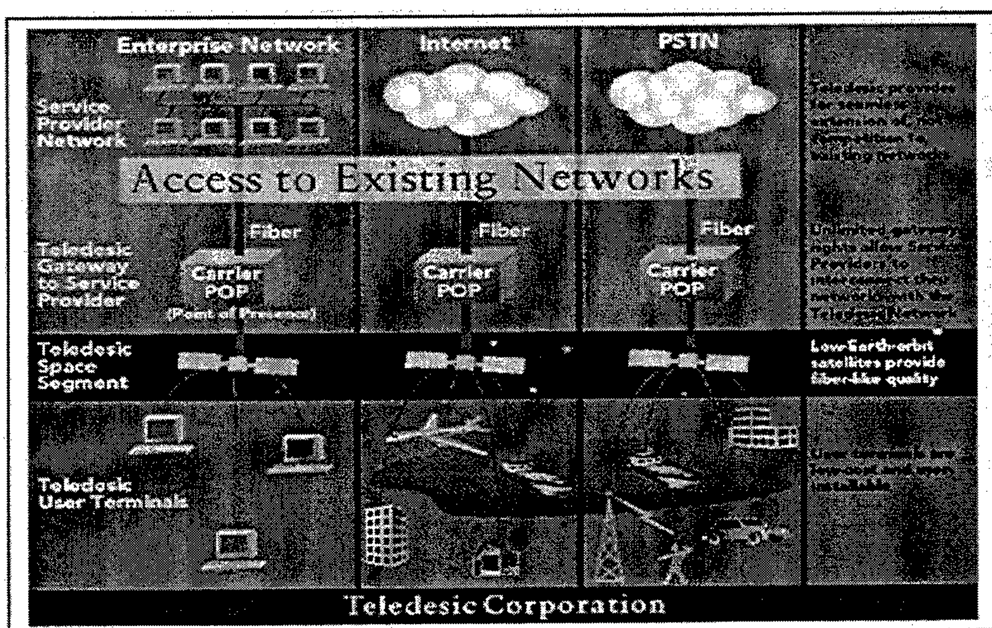

Figure 14. Teledesic Network. [Ref. 34]

8. Communications Architecture

The Teledesic Network uses fast packet switching technology based on the Asynchronous Transfer Mode (ATM) technology now being used in Local Area Networks (LAN), Wide Area Networks (WAN), and the Broadband Integrated Services Digital Network (B-ISDN). All communication is treated identically within the network as streams of short fixed-length packets. Each packet contains a header that includes address and sequence information, an error-control section used to verify the integrity of the header, and a payload section that carries the digitally encoded voice or data. Conversion to and from the packet format takes place in the ground-based terminals. The fast packet switch network also combines the advantages of a circuit-switched network (low delay digital pipes), and a packet-switched network (efficient handling of multi-rate data). Fast packet switching technology is ideally suited for the dynamic nature of a LEO network. [Ref. 37]

Each satellite in the constellation is a node in Teledesic's fast packet switch network, and has inter-satellite communication links with eight adjacent satellites. This interconnection arrangement forms a non-hierarchical "geodesic," or mesh, network and provides a robust network configuration that is tolerant to fault and local congestion [Ref. 39]. In hierarchical systems, when a node or link fails, service for entire sections of the network may be disrupted. In contrast, the Teledesic Network's high coverage redundancy, rich connectivity, and autonomous adaptive packet-routing capability limit or eliminate the effect of the failure of a node or link. Adjacent spacecraft in the web share the workload of their disabled neighbor, until it can be repaired or replaced by an on-orbit spare, while maintaining a constant level and quality of service. [Ref. 30]

The topology of this 288 satellite LEO constellation is dynamic. Each satellite keeps the same relative position relative to other satellites in its orbital plane. Its position and propagation delay relative to earth terminals and to satellites in other planes changes continuously and predictably. In addition to changes in network topology, as traffic flows through the network, queues of packets accumulate in the satellites, changing the waiting time before transmission to the next satellite. All of these factors affect the packet routing choice made by the fast packet switch in each satellite. These decisions are made continuously by a microprocessor within each satellite node using Teledesic's distributed adaptive routing algorithm. This routing algorithm adapts the packet routing decisions to the current network configuration and to the mapping between satellite scanning beams and fixed cells on Earth. The algorithm uses information broadcast throughout the network by each satellite to learn the current status of the network and to select the path of least delay to route each packet to its destination. The algorithm also controls the connection and disconnection of network inter-satellite links. [Ref. 30]

The network uses a "connectionless" protocol, using a combination of destination-based packet addressing and a distributed, adaptive packet routing algorithm to achieve low delay variability across the network. Each packet carries the network address of the destination terminal, and each node independently selects the least-delay route to that destination. Packets of the same session may follow different paths through the network. [Ref. 30] The required packets are buffered, and if necessary resequenced, at the destination terminal to eliminate the effect of timing variations. Teledesic has performed extensive and detailed simulation of the network and adaptive routing algorithm to verify that they meet Teledesic's network delay and delay variability requirements. [Ref. 28]

Teledesic's network-control software, fast-packet switch architecture and richly inter-connected network provide many possible pathways through the network for each individual packet. This provides a degree of security and assurance previously unavailable. In essence, the system reliability is built into the constellation as a whole rather than being vulnerable to the failure of a single satellite. To achieve high system capacity and channel density, each satellite is able to concentrate a large amount of capacity in its relatively small coverage area. Overlapping coverage area plus the use of on-orbit spares permit the rapid repair of the network whenever a satellite failure results in a coverage gap. [Ref. 36]

The Teledesic Network will provide a quality of service comparable to today's modern terrestrial communication systems, with bit error rates less than 10^{-9}, and a link availability of 99.9 percent over most of the United States. The 16 kbps basic channel rate supports low-delay voice coding that meets "network quality" standards. The Network will offer high-capacity, "bandwidth-on-demand" through standard user terminals. Channel bandwidths range from a minimum of 16 kbps up to 2.048 Mbps (E1) on the uplink, and up to 28 Mbps on the downlink. Teledesic also will be able to provide a smaller number of high-rate channels at 155 Mbps to 1.24416 Gbps (OC-24) for gateway connections and users with special applications. Most users will have two-way wideband terminal connections that provide up to 64 Mbps on the downlink and up to 2 Mbps on the uplink. This represents access speeds up to 2,000 times faster than today's standard analog modems. The low orbit and high frequency allow the use of small, low power terminals and antennas, with a cost comparable to that of a notebook computer. [Ref. 28]

Teledesic will use the small, earth-fixed cells both for efficient spectrum utilization and to respect countries' territorial boundaries. Within a 53 by 53 km cell, the Network will be able to accommodate over 1800 simultaneous 16 kbps voice channels, 14 simultaneous E1 channels, or any comparable combination of channel bandwidths. The Teledesic Network is designed to support a peak capacity of 1,000,000 full-duplex E1 connections, and a sustained capacity sufficient to support millions of simultaneous users. The system design also allows a graceful evolution to constellations with much higher capacity without altering the system architecture, spectrum plan, or user terminals. The network capacity estimates assume a realistic, non-uniform distribution pattern of users over the Earth's land masses. Some cells will generate over 100 times the traffic of the "average" cell. [Ref. 38]

The ability to handle multiple channel rates, protocols and service priorities provides the flexibility to support a wide range of applications including the Internet, corporate Intranets, multimedia communication, LAN interconnect, etc. In fact, flexibility is a critical network feature, since many of the applications and protocols Teledesic will serve in the future have not yet been conceived.

D. GLOBALSTAR

On 9 September 1998, Globalstar, Qualcomm and Telecommunications par Satellites Mobiles (TE.SA.M.) proudly conducted their first public Globalstar phone call at the sixth Satel Conseil Symposium in Paris, France [Ref. 39]. While Globalstar officials were lauding this accomplishment, however, a disaster was about to occur across the continent. That same day, a Russian Zenit-2 rocket exploded shortly after launch from the Baikonur cosmodrome, destroying 12 Globalstar satellites [Ref. 40]. Although

the satellites lost were fully insured, Globalstar experienced a large setback in its timeline to begin service with all 48 satellites in orbit. This was a particularly disappointing event considering that Iridium, Globalstar's closest competitor, already had its entire constellation in orbit [Ref. 41]. Globalstar now intends to begin service by the end of 1999 with only 32 satellites in orbit, filling the remainder of the constellation with subsequent launches.

1. Orbit and Constellation

The Globalstar system will utilize a total of 48 operational satellites placed in eight orbital planes. This will provide continuous service coverage from 70 degrees South latitude to 70 degrees North latitude.

a. Constellation Geometry

The Globalstar satellites will reside in what is known as a Walker constellation, or 48/8/1/52 degrees/1389, (48 satellites, uniformly distributed in eight planes, with a phase shift of 7.5degrees from one plane to another, inclination 52 degs. and altitude 1389 km [Ref. 42]), as depicted in Figure 15.

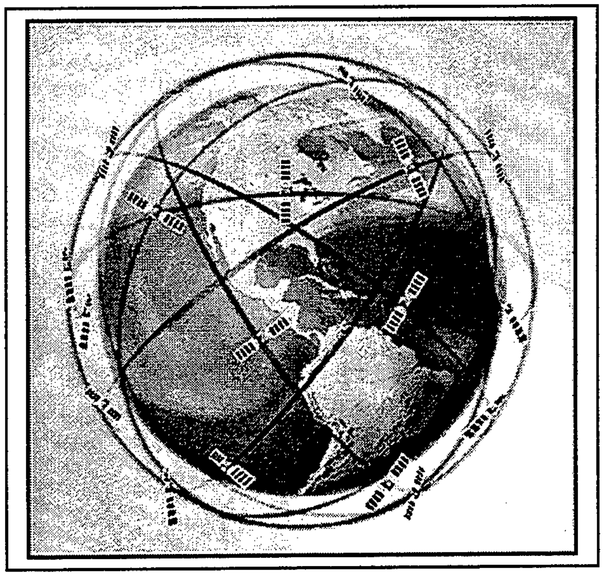

Figure 15. Globalstar Constellation. [Ref. 43]

b. Constellation Effectiveness

The Walker constellation was chosen for its world-wide coverage, from 0 to 70 degrees latitude. While this geometry does provide for "world-wide" coverage, it does not provide "global coverage," 0 to 90 degrees latitude, like its greatest competitor, Motorola's Iridium. To provide its "global coverage," the Iridium system will utilize polar orbits and require a total of 66 satellites. While this is a tradeoff in performance for Globalstar, it will provide a cost-cutting measure for Globalstar service.

The large number of satellites per orbital plane will provide high average elevation angles and in turn produce the propagation margins required for mobile communications. Additionally, the low altitude nature of its LEO system provides a variety of other benefits to this venture. First, the satellites can be placed in orbit by a wide variety of launch vehicles, as discussed earlier. Secondly, the power required to

reach a LEO satellite by a ground user is substantially less than reaching a geostationary satellite, for example. This allows for the user to place the transmitter/phone next to the ear without fear of harmful physiological effects and also allows for the use of a much smaller transmitter/receiver antenna. A third advantage of LEO orbits is the near real time transmission of data, precluding the delays and echoes experienced in geostationary communication systems. Lastly, LEO systems provide a far greater degree of redundancy through their large number of satellites, whereas geostationary systems can become useless with the loss of just one satellite.

2. Space Segment

The space segment of the space mission architecture includes both the satellite bus and its payload. The bus provides services, such as orbit and attitude maintenance, power, structure, data handling, and climate control, while the payload contributes those items required for interaction with the user [Ref. 44]. The mass of a Globalstar satellite (see Figure 16.) is approximately 450 kg, and the first generation spacecraft are designed to operate at full performance for 7 1/2 years.

a. Spacecraft Bus

The trapezoidal shape of the satellite helps to conserve volume and allows for the mounting of several spacecraft within the fairing of the launch vehicle. The Globalstar satellites are stabilized with a three-axis attitude control system, and are some of the first satellites to utilize Global Positioning System (GPS) for tracking orbital position and attitude. Most attitude control functions are accomplished through momentum wheels and magnetic torquers, with the five thrusters used primarily for orbit raising and maneuvering.

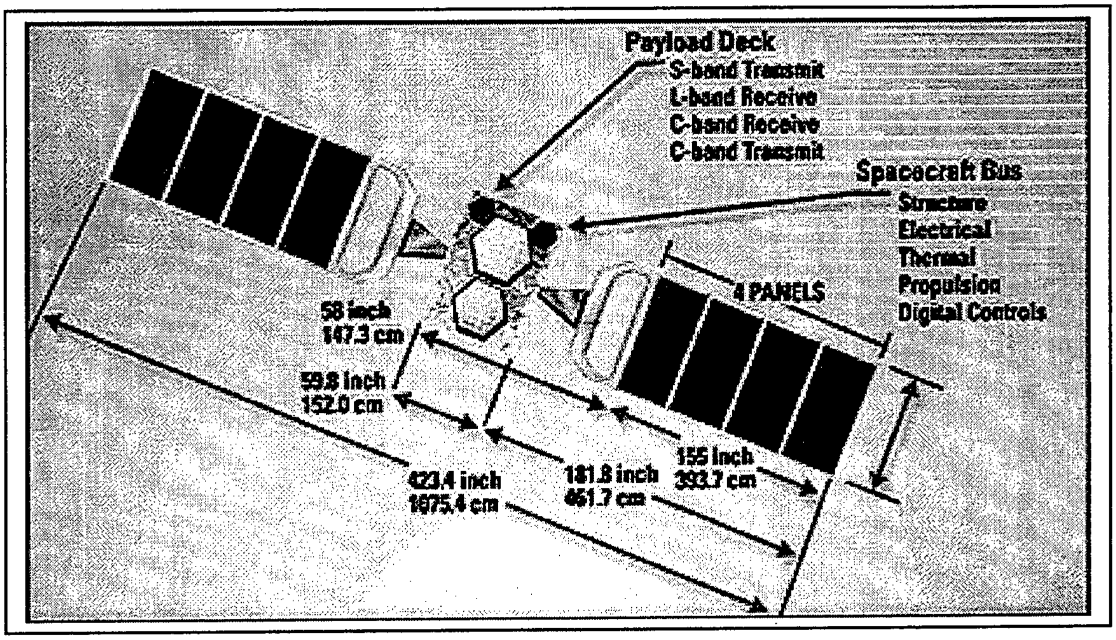

Figure 16. Globalstar Satellite. [Ref. 43]

The satellite receives its power through two 155-inch long solar arrays. The solar arrays also feed batteries to provide power when the sun is not available or eclipsed. The solar panels are designed to provide 1,100 W of power and automatically adjust to provide maximum sun exposure. While the satellites do transfer information to and from the ground, no onboard processing is done. This "bent-pipe" design maintains a low-cost satellite architecture, which is extremely important considering that 48 spacecraft will be utilized in the Globalstar constellation. [Ref. 43]

b. Spacecraft Payload

The payload of the Globalstar satellite, communications equipment, is mounted to the bus's Earth deck. The payload consists of C-band antennas, for communicating with Globalstar's Gateways, and L- and S-band antennas for communicating with user terminals. These phased array antennas project 16 beams on the Earth's surface, providing a service footprint several kilometers in diameter. [Ref. 43]

3. Launch Segment

Although the launch segment of a space mission is the shortest in duration, it is one of the most expensive segments and provides the greatest risk. It is, therefore, one of the most important facets of the space mission. For example, a Delta II launch mission costs approximately $100 million for the rocket and payload combined, with each of the satellites costing about $13 million. [Ref. 45] The Globalstar constellation of satellites will be launched by three different launch vehicles, the Boeing Delta II, the Russian Zenit-2, and the French Soyuz-Icare. All three vehicles are Expendable Launch Systems, meaning that the launch vehicle is not recovered after use. The Delta II produces 359,337 kgf of liftoff thrust and carries a Globalstar payload of four satellites with a total mass of 1,776 kg. The Zenit-2 provides 769,880 kgf of liftoff thrust and carries a LEO payload of 13,740 kg, including 12 Globalstar satellites. Finally, the Soyuz-Icare makes 411,116 kgf of liftoff thrust and carries a LEO payload of 7,050 kg, including four Globalstar satellites. The Delta II launches will take place at Cape Canaveral, Florida, with the Zenit-2 launches occurring in Baikonur, Kazakhstan, and the Soyuz-Icare launches taking place in France. [Ref. 43]

4. Ground Segment

The ground segment of the Globalstar system provides the processing muscle required for this complex communications network. The ground segment includes the Gateways, Ground Operations Control Centers, Satellite Operations Control Center, and the Globalstar Data Network. Due to the bent-pipe architecture of the Globalstar satellites, the ground segment of the system is of utmost importance, as it performs the

majority of work in the system. The ground segment provides the backbone for the complex communication and data network incorporated in Globalstar.

5. Communication Architecture

a. Gateways

More than 30 Gateways in the Globalstar system will interconnect the satellite wireless network with ground based Public Switch Telephone Networks (PSTN) and Public Land Mobile Network (PLMN) infrastructure. [Ref 46] The Gateway takes the signal received from the satellite and patches it into the existing land communications systems, whether they be line or wireless. This interoperability between Globalstar and local telephone and cellular companies is assured and the subscriber maintains a convenient single point for billing. [Ref. 43] Each Gateway has the capacity to connect up to 1,000 users to these public telephone systems simultaneously. [Ref. 47]

b. Ground Operations Control Centers

"The Ground Operations Control Center's (GOCC) are responsible for planning and controlling satellite utilization by Gateway terminals, and for coordinating this utilization with the Satellite Operation Control Center." [Ref. 35] GOCC's control all ground-based assets and schedule the communication links between the satellites and Gateways. The Gateways and satellites then use these parameters to operate autonomously.

c. Satellite Operations Control Center

The Satellite Operations Control Center (SOCC) controls the spacecraft in the Globalstar satellite constellation. Along with a primary SOCC located in San Jose, CA, a backup SOCC, located in Sacramento, CA, provides redundant service in the case

of a primary SOCC failure. These facilities are charged with controlling orbits, tracking satellites and providing Telemetry and Command functions to achieve these goals. SOCC's also serve as the health and status monitors of the Globalstar constellation. Furthermore, the SOCC is responsible for monitoring all launch and deployment activities.

d. Globalstar Data Network

The Globalstar Data Network (GDN) provides the communications and data link between the different components of the ground segment, including the Gateways, GOCC and SOCC. The GDN enables the Gateways, GOCC's and SOCC to remain in continuous contact with one another through a wide-area network type of infrastructure. This kind of link is imperative with the tremendous requirements placed on the Globalstar ground system. [Ref. 48]

6. C^3 Architecture

The command, control and communications architecture is truly the heart of the Globalstar system. This is not surprising, considering that Globalstar is primarily a communications system. To achieve the lowest possible cost satellite communications, Globalstar uses a complex system of signal routing through terrestrial systems, including local and regional service providers. A Globalstar user call is first routed through an existing local cellular service, if available. In this case, no satellite communications are required. If cellular service is not available, however, the Globalstar call will then be routed to an overhead satellite. The call is then relayed from the satellite to a Gateway (see Figure 17). The Gateway in turn forwards the call through existing ground services to its destination. [Ref. 43]

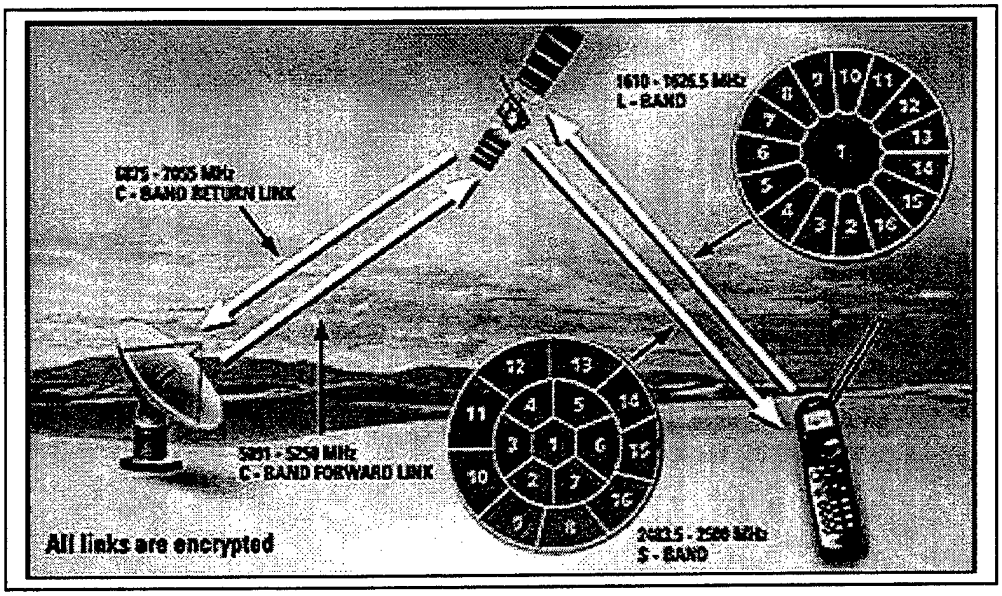

Figure 17. Globalstar Frequency Plan. [Ref. 43]

a. Frequency Plan

Globalstar communications take place in the C, L and S-bands. The user terminal contacts the satellite via a 1.6 GHz L-band signal and receives signals from the satellite in the 2.5 GHz S-band. Likewise, Gateways contact satellites via a 7 GHz C-band signal and receive on a 5 GHz signal. Globalstar communications can be broken down into two links, a forward link, which consists of a Gateway communicating with a satellite, that in turn communicates with the user terminal. The other link, a reverse link, is just the opposite. In the forward link, a Gateway will produce an effective isotropic radiated power (EIRP) of 41dBW and yield an Eb/No at the user terminal of 3.9 dB. The return link will see an EIRP of –9.2 dBW at the user terminal and an Eb/No of 5.7 dB at the Gateway. These values provide for extremely high-quality voice and data transmissions. [Ref. 47]

b. Frequency Reuse and Cell Management

Frequency spreading is required by radio regulations, particularly those concerning limitations of power flux emitted by the user terminal and satellite. Transmission systems must use the power of satellites to maximize capacity, share the spectral resource with other services, obey regulations in order to avoid interference, offer high availability with excellent quality, and avoid "self-interference" coming from multiple coverages. [Ref. 42] To accomplish these goals, Globalstar utilizes a technique known as code division multiple access (CDMA).

CDMA, now also known as IS-95, allows ground stations to receive two different signals from two different satellites simultaneously. [Ref. 49] This provides continuous, transparent handoffs between satellites. CDMA also permits users to share time and frequency allocations by assigning each user a particular code. The receiver then accepts only those transmissions that it recognizes as coming from the user's designated unique code. By doing so, Globalstar can handle large numbers of users at the same time, operating on the same frequency channel. In addition to simply listening for a properly encoded message, Globalstar can also control power in such a way that less discrete signals are amplified while others are de-amplified.

Globalstar users will communicate via three types of user terminals, fixed, mobile and personal. The fixed terminal will look like any ordinary fixed line telephone booth, but will offer wireless communications in remote areas with very little setup. In this format, communications can be offered to remote, developing areas before the infrastructure of a landline is developed. Mobile users will communicate via a car-mounted system. This system will offer the accoutrements of an ordinary mobile cellular

phone, including hands-free usage and battery charging facilities. The personal, dual-mode user terminal will be the most widely used of the three terminal types. These terminals will closely resemble a common cellular phone in size, shape and function. As mentioned earlier, the user will first be connected via existing cellular networks if available, but in the event no such service can be utilized, the call will be completed through the Globalstar system. In any event, each call will appear to be like any cellular telephone call.

E. ADVANTAGES OF LEO SATELLITE SYSTEMS

- The low orbits allow them to transmit signals without the troublesome half-second delay characteristic of geosynchronous satellites.
- Because they are lighter and on lower orbits, they are cheaper to launch.
- Signals relayed by the LEO's remain stronger because of the lower orbit, so they are compatible with handsets the size of cellular phones.
- The low altitude of the satellites allows easy radio links with portable cellular radiotelephones on earth, using small antennas rather than satellite dishes. It also supports reuse of radio frequencies, in a similar fashion to land-based cellular systems.
- The system solves the problem of low-orbit satellites "disappearing over the horizon'" by combining a large number of satellites in a space-based, inter-satellite switching system.
- Designed to complement, not compete with, land-based cellular systems. Land-based cellular will remain the most efficient way to serve high-

density areas, whereas LEO satellites will bring communications to remote or sparsely populated areas that lack communications.

- LEO satellites and terrestrial cellular will work together to eventually provide a seamless communications service for the entire world.
- For low-density areas lacking cellular phone networks, LEO satellites will be an ideal alternative for mobile telephone service. In sparsely populated or underdeveloped areas lacking basic telephone service, satellites can be a foundation for an eventual ground telephone system.
- For ships and aircraft, LEO satellites will provide voice or data links and positioning information without the sophisticated on-board telecommunications hardware now required. Since satellites are not dependent on land-based communications links, they will also play a crucial role in crisis response as well as disaster-recovery efforts following earthquakes, hurricanes or other natural calamities.

F. MILITARY APPLICATIONS OF SATELLITE COMMUNICATIONS

The application of a system such as Iridium, Teledesic, or Globalstar has limitless possibilities in the military. Marines in the field could reduce the weight of their communication equipment drastically while enhancing the level of their communications. Navy ships can enhance their overall communication abilities without the added concerns of large antennas and miles of wire throughout the ships. If implemented properly, the ability to communicate from anywhere in the world with a hand held phone will significantly enhance the fighting capability of the Armed Services. Any unit no matter

how large or small could be provided the same level of connectivity afforded to only the senior most personnel at this time.

Without question there is a role for commercial satellite communications in support of world-wide military operations. The requirement to rapidly communicate over long distances has resulted in an increased dependence upon satellite communications for DoD operations. During Operations Desert Shield and Desert Storm and as recent as Operation Joint Endeavor in Bosnia, communications planners realized existing MILSATCOM systems lacked sufficient capacity to support the enormous communications requirements for JTF command operations. As a result, an integrated architecture using commercial satellite communications systems to augment existing, overburdened, military communications systems is being pursued to resolve today's shortfalls. At the urging of Congress in 1992, DoD began the Commercial Satellite Communications Initiative to investigate ways in which the DoD could more effectively, and more inexpensively, make use of substantial on-orbit commercial communications capacity and thereby lessen its reliance on military systems. The first outgrowth of that study was the DOD's 1993 policy on the use of commercial SATCOM. [Ref. 46]

Under the Commercial Satellite Communications Initiative (CSCI), DoD planned to lease transponders, not connections, on more than a single satellite and from the system owner, not from the communications service provider. Following in the spirit of the CSCI, the U.S. Navy has been aggressively pursuing the use of commercial wideband satellite communications systems as an augmentation to existing military systems. The goal of the CNO Special Project Challenge Athena has been to provide the necessary communications throughout the fleet to allow JTF commanders afloat the ability to

actively participate in joint command decisions and operations. In future visions of Joint Vision 2010 (JV 2010) and the Navy's Information Technology for the 21st Century (IT-21), the increased bandwidth and area coverage requirements that can be met by the LEO systems will dramatically enhance MILSATCOM systems. [Ref. 46]

JV 2010 is the conceptual template for how our forces will achieve dominance across the full range of military operations in the future. The emerging operational concepts of JV 2010 can be characterized as "Network Centric" and the vision of future warfare as "Network Centric Warfare." One goal of JV 2010 is to provide warfighters with accurate information in a timely manner. Information technology improves the ability to see, prioritize, and assess information. The fusion of all-source intelligence with sensors, platforms, command centers, and logistics support centers will allow operations to move faster. Advances in computer processing and the global network umbrella of the LEO systems could provide the capability to collect, process and display relevant, fused data to thousands of locations simultaneously. This integrated civilian and military SATCOM system will ensure that the data is distributed on a real-time basis, making it possible for warfighters to use information most effectively. [Ref. 46]

One example of an existing operational architecture that employs network centric operations to increase combat power is the Cooperative Engagement Capability (CEC). The operational architecture of CEC increases combat power by networking the sensor, C4 and shooters of the CVBGs platforms to develop a sensor engagement grid. The CEC sensor grid fuses data from multiple sensors thereby enabling quantum improvements in timeliness, track accuracy, continuity, and target ID over stand-alone sensors. To provide the networking communications bandwidth required for the integration of sensors and

weapons systems, a robust and flexible communications system such as Iridium, Teledesic, or Globalstar would be a preliminary requirement. These systems could be integrated into the idea of Network Centric Warfare as part of the information grid. [Ref. 49]

Present day acquisition focuses heavily on procurement of intelligence gathering and production systems as well as sophisticated weapons platforms and munitions and to a much lesser extent on the communication links to support these elements. However, modern warfighting intelligence and weapons systems require a vast transmission capacity to support them. Command, Control, Communications, Computers and Intelligence (C4I) systems are force multipliers which allow smaller, better equipped warfighting forces to be more effective. In this era of right-sizing, force-multipliers, like C4I systems, and mainline commercial technologies have become increasingly important to mission success. [Ref. 50]

Although large volumes of intelligence information are available to warfighting CINCs, today's MILSATCOM system has insufficient capacity to transmit this information, in timely fashion, from national collection and processing facilities to JTF and deployed forces. Requirement growth has historically outpaced satellite communications capabilities, and the shortfall is becoming greater every year. [Ref. 46]

The currently planned orbiting capacity of MILSATCOM will not keep pace with the increase in capacity required by new services such as video and imagery, and the added demands for information to feed new sensors and weaponry. As the demand for SATCOM bandwidth increases, the probable method for allocating circuits will be to assign MILSATCOM only circuits to protected systems first. The remaining circuits will

be allocated to commercial SATCOM systems. Iridium, Teledesic, or Globalstar should be among the commercial systems used. [Ref. 46]

These LEO systems are characterized by a wide variety of services, capabilities, and costs allowing flexibility for DoD procurement. Once a SATCOM requirement has been designated as a candidate for commercial satellite implementation, the required attributes of data rate, power, and coverage of a DoD SATCOM requirement can become the focus for matching up with the LEO system. Iridium, Teledesic, and Globalstar will provide DoD with higher power transponders, new frequencies, and enhancements in antenna technology that will extend the reach of services to smaller platforms such as cruisers, destroyers and platoon size units. [Ref. 46]

The integration of Iridium, Teledesic, or Globalstar into the MILSATCOM satellite architecture will enable DoD to meet some of its goals in programs such as JV 2010 and IT-21. They could provide the networking for DoD Internet functions such as email and the World Wide Web as well as transport for tactical and non-tactical data. The system's low latency will allow it to use standard Internet protocols for ease of systems integration and the use of off-the-shelf applications, all goals of JV 2010 and IT-21. [Ref. 46]

Through use of a LEO Satellite Network, the Joint Maritime Communications Strategy (JMCOMS) networks can interface through Standardized Tactical Entry Points (STEP) to the packet data networks of the other services to include the Army's "Enterprise" Network and the Air Forces' "Horizon" Network. Teledesic will interface with the SIPRNet/NIPERNet through the evolving shore communications infrastructure. JMCOMS addresses both technical and implementation challenges of integrating

Teledesic with a clear strategy. Rapid advances in telecommunications technology and products is key. Many off-the-shelf products for routing, addressing, networking and network management are available and compatible with the LEO satellite systems. DOD should be able to inexpensively install or modify the commercial satellite terminals for use on DOD platforms. [Ref. 46]

LEO satellite systems can bridge the gap in voice and high data rate communications until military satellite communications systems can provide sufficient throughput to meet the warfighter's requirements. Once future requirements are met through enhanced MILSATCOM systems, the LEO systems can provide an on-demand surge capability during contingency operations. High data rate duplex systems such as military or commercial wideband satellite communications can then be used for virtual theater injection by bringing high data rate information such as tactical imagery back to regional terrestrial networks. Depending on the future acquisition strategies of DOD toward Iridium, Teledesic, and Globalstar, coverage and availability could be assured at a reasonable cost. [Ref. 46]

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V. COMMUNICATIONS MODELING AND SIMULATION

A. MODELING AND SIMULATION

This chapter explores the use of modeling and simulation as a tool in understanding the current naval surface fire support communication architecture and the proposed architecture that support the ELB concepts of OMFTS and STOM. The models and supporting employment scenarios are based on research performed while investigating OMFTS doctrine and the concept of operations employed by the U.S. Marine Corps Warfighting Lab's Hunter Warrior experiment and the U.S. Navy's Fleet Battle Experiments. Two models were developed and tested employing a PC based, object oriented modeling and simulation tool called Extend (version 4.03) developed by Imagine That! Incorporated. Extend, an easy-to-use graphical simulation tool, allows the user to model complex discrete or continuous systems while varying performance parameters. [Ref. 51,52]

1. Background and Terminology

A model is a logical description of how a system performs. Simulations involve designing a model of the system, carrying out experiments on it through time, and measuring the behavior of the model. Models are increasingly being used because they enable one to test systems at a fraction of the cost without actually undertaking the activities to construct a real world physical representation of the system. This is invaluable in the initial concept and development of any new system and its supporting principles. It allows evaluation of ideas and identification of inefficiencies before expending capital and resources to the final product. Simulation is also important because it is used to: gain insight and stimulate creative thinking toward a concept;

identify problems before implementation; confirm all variables; and finally, to strengthen the integrity and feasibility of a concept. [Ref. 52] The principle benefit of a model is that design begins with a simple approximation of a process that is gradually refined as understanding of the process improves. Thus, models can always be changed to improve accuracy.

2. Extend Software

Extend was chosen because it is a popular tool for high level, concept design. Extend requires only a 486, or Pentium Pro computer and runs on Windows 3.1, 95, 98 or NT by Microsoft or MacIntosh or Power MacIntosh by Apple. Also, it is user-friendly and comparatively inexpensive. Extend is used extensively by Navy organizations conducting research in OTH communication concepts, such as SPAWAR, and the Naval Postgraduate School. The software uses pre-built object blocks that are the foundation of an Extend model. They emulate user-selected functions, actions, and processes of the model.

Represented by icons, blocks are assembled by "dragging and dropping" from the Graphical User Interface (GUI) tool bar to the working space. The user then connects the blocks in logical order, or desired sequence, while also entering performance parameters, or behaviors, into each block through its associated dialog page. Animation allows items to be followed during simulation. As the model becomes larger and more complex, the user can group blocks, and form process hierarchies with associated inputs and outputs. Simulation results are displayed using graphs, tables, sensitivity analysis, and user-developed notebooks for input and output performance of data. [Ref. 51] Because

network activities are event driven, discrete event simulation is the design basis for the modeled scenarios.

3. Design Steps

The scenario based network models follow this design sequence: define the physical communication architectures required to support the operational concepts; develop and build the model through a stepwise, iterative process that includes representation of links, nodes, and interfaces; run the simulation, analyze the results; and draw conclusions based on model results. This process is presented in the following section. The two models are presented in their entirety and then broken down into each individual group and what they represent. A discussion of the simulation results follows each presentation of the models.

B. THE EXTEND MODELS

1. Design Parameters

The design parameters modeled include bandwidth loading based on user message input from previous exercises, delays, and system characteristics. These models assume that the maximum bandwidth is used when all units are acting independent of one another with sea-based command and control and naval fire support. The user groups are selected based on the Marine Corps' pyramid command and control organizational structure of "threes." For example, the basic infantry unit is the fire team. There are three fire teams per squad, three squads per platoon, and three platoons per company. Also, there are three companies per battalion and three battalions per regiment.

The first model discusses a battalion of users whereas the second model represents a regiment's worth of fire support messages. The user groups have established

communication links to Navy ships for NSFS. The assumptions for both scenarios are summarized as follows:

- Command and control is sea-based.
- Units, companies, operate independently of one another.
- Message inter-arrival times are random. Therefore, the performances of the architecture outputs are based on random behavior of the nodes.

2. Current Naval Gunfire Architecture

a. Overview

This model represents the fire support messages of a MEU size element. It concentrates on three infantry companies' calls-for-fire (CFF). The NGF architecture is designed for messages to be sent from an infantry company to a Navy ship, which is in direct support (see Figure 18). This model can be tripled to show that total amount of time it would take a regiment to send its total messages. The initial CFF is shot and the follow-on "adjust fire" messages are shot as the probability of "steel-on-target" increases as each call is prosecuted. As a CFF is processed, the probability of the round hitting its target increases from 70% to 80%, 90%, and finally 100%. The time delay for each message being sent is directly proportional to the bandwidth (BW), 2.4 kbps, divided by each message size. Also, time delays were put into the system to replicate the time it takes Marines to properly send the entire CFF message.

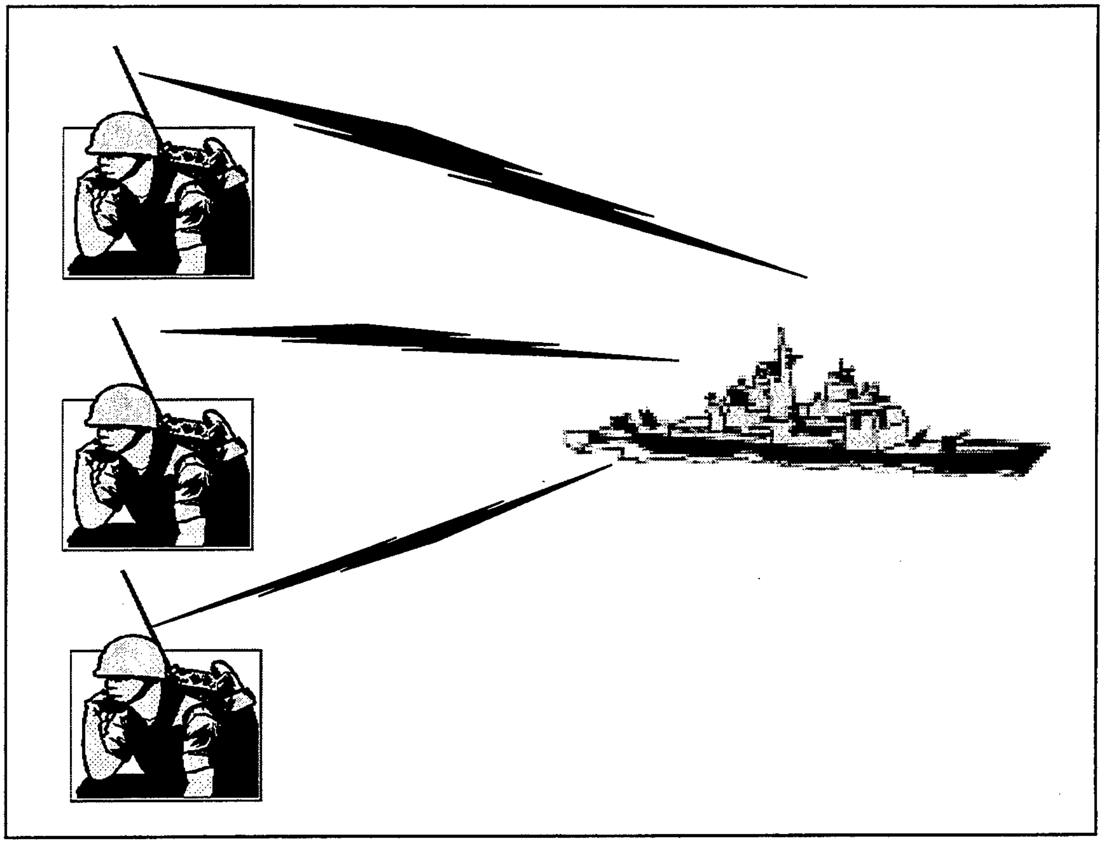

Figure 18. Naval Gunfire Support Architecture for Model 1.

b. User Group

Each user group represents an infantry company. The Marine company block represents nine squads (see Figure 19). Based on the after action reports from the Hunter Warrior '97 exercise and the ITT study mentioned in chapter III, a 256-bit position report (POSREP) message is sent every five minutes. A 700-bit situation report (SITREP) message is sent every 15 minutes. Ten percent of the squads (approximately three squads) encounter firefights at various times. When a squad is engaged in a firefight, a 750-bit CFF message is sent each minute for fifteen minutes based on the Hunter Warrior experiment results.

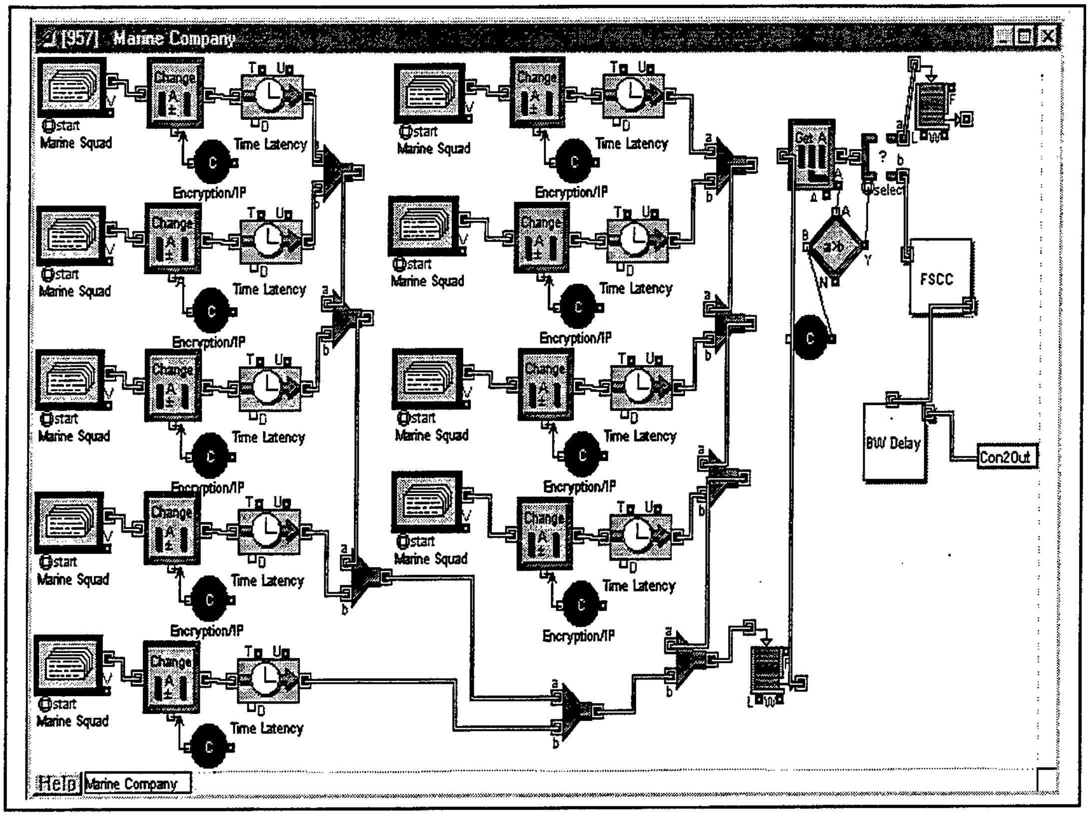

Figure 19. Marine Company Hierarchical Block in Extend. [Ref. 51]

A POSREP is sent every five minutes and a SITREP every 15 minutes. These messages are sent to an exit to signify that they are not CFF messages. The CFF messages are sent through the ship for fire prosecution. Figure 20 presents the messages that are sent out of the program blocks.

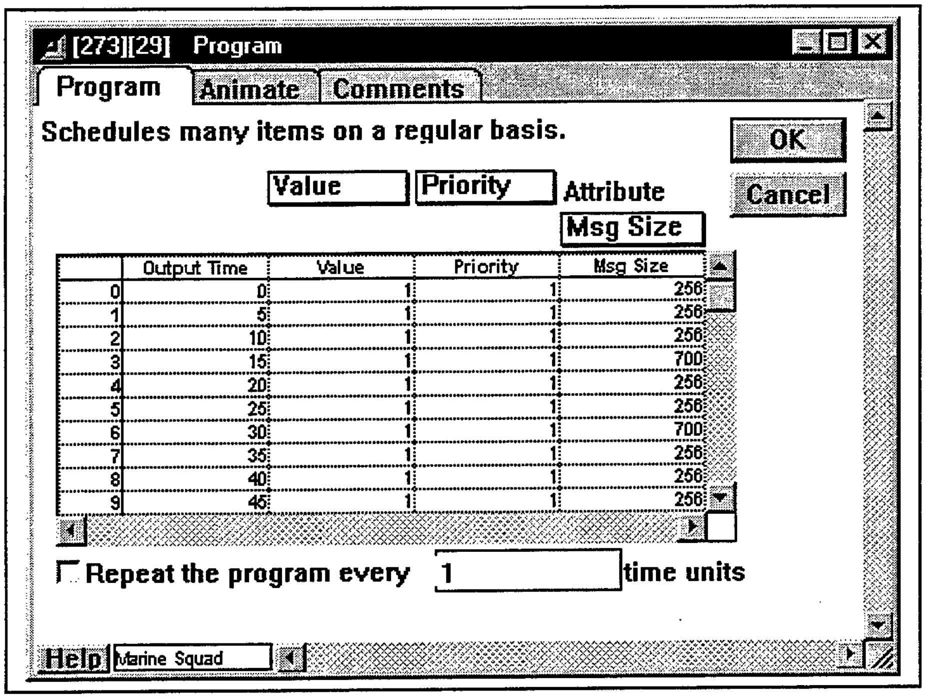

Figure 20. Messages Sent from Marine Companies in Extend. [Ref. 51]

As discussed earlier, there are time delays for the messages to reach the ship. The first time delay is the approximate amount of time it takes a Marine to completely pass a message by voice. The second message time delay is the delay associated with the type of communication equipment used. This model uses an AN/PRC-104, high frequency (HF) radio with a BW of 2.4 kbps. The message size is divided by the BW to get the second time delay. There is also an initial time delay on the ship to represent the time a sailor takes to copy down the CFF message.

c. Naval Gunfire Support Ship

When the message reaches the ship there is a delay to represent the sailor receiving the message. The message is then sent through a process going through the

navigation plot, a gun plot, and a 5" 54 console. The message is then passed to a fire control computer if the three plots match. Figure 21 shows this process.

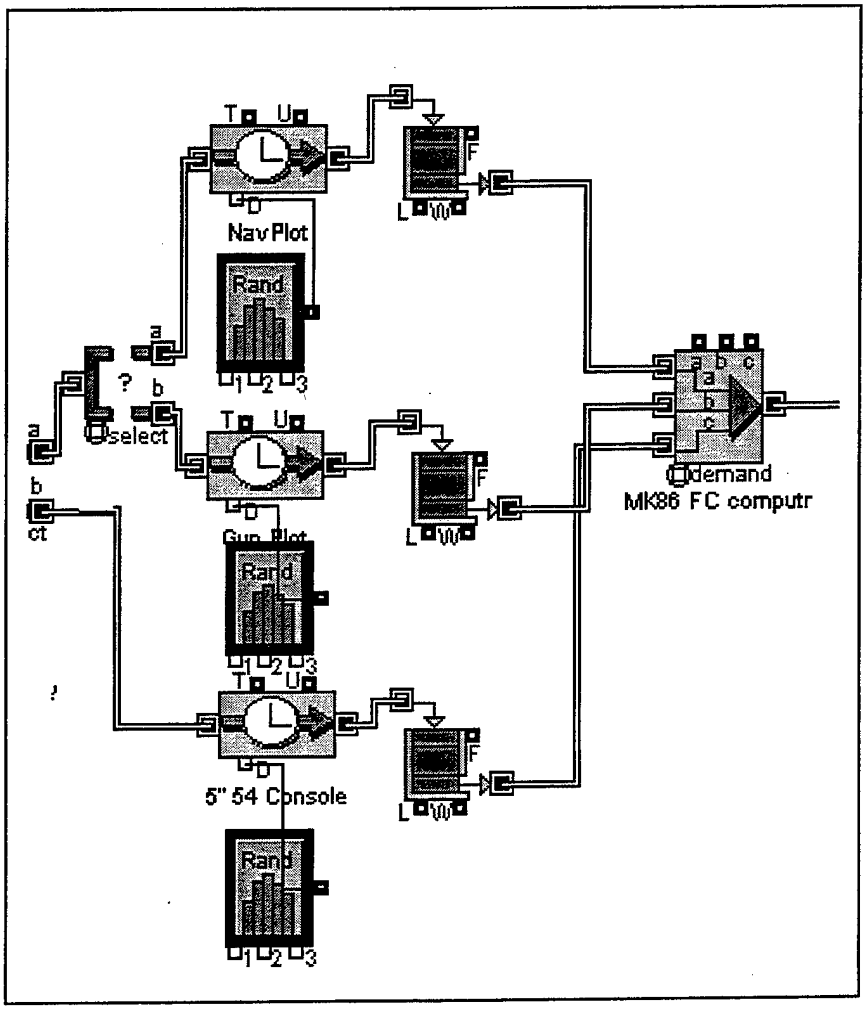

Figure 21. Naval Gunfire Support Ship Modeled in Extend. [Ref. 51]

Finally, the message passes through the system and the shot is fired. "Fire adjustment" messages are then sent and the probability of hitting their target is increased. When the fifth shot is fired the round has a 100% chance of getting "steel on target."

3. Proposed ELB Naval Surface Fire Support Architecture

a. Overview

The ELB NSFS architecture represents a Marine Expeditionary Brigade (MEB) size force comprised of an infantry regiment supported by three ships in general support. The Marine Corps no longer use MEB's but this model can be scaled larger to a Marine Expeditionary Force (MEF) size element and a MEF forward may be regimental size. An infantry regiment is composed of three infantry battalions and each battalion has three infantry companies. The ELB NSFS architecture (see Figure 22) is designed for messages to be sent from an infantry company into a LAWS computer onboard a command ship via the Iridium satellite system. Once LAWS decides which ship will shoot the request, the message is sent to that ship and the round is fired. The time delays for the messages are directly proportional to the message size divided by the BW used by the Iridium system. Small delays have been placed in LAWS for database checks and in the communications links amongst the ships.

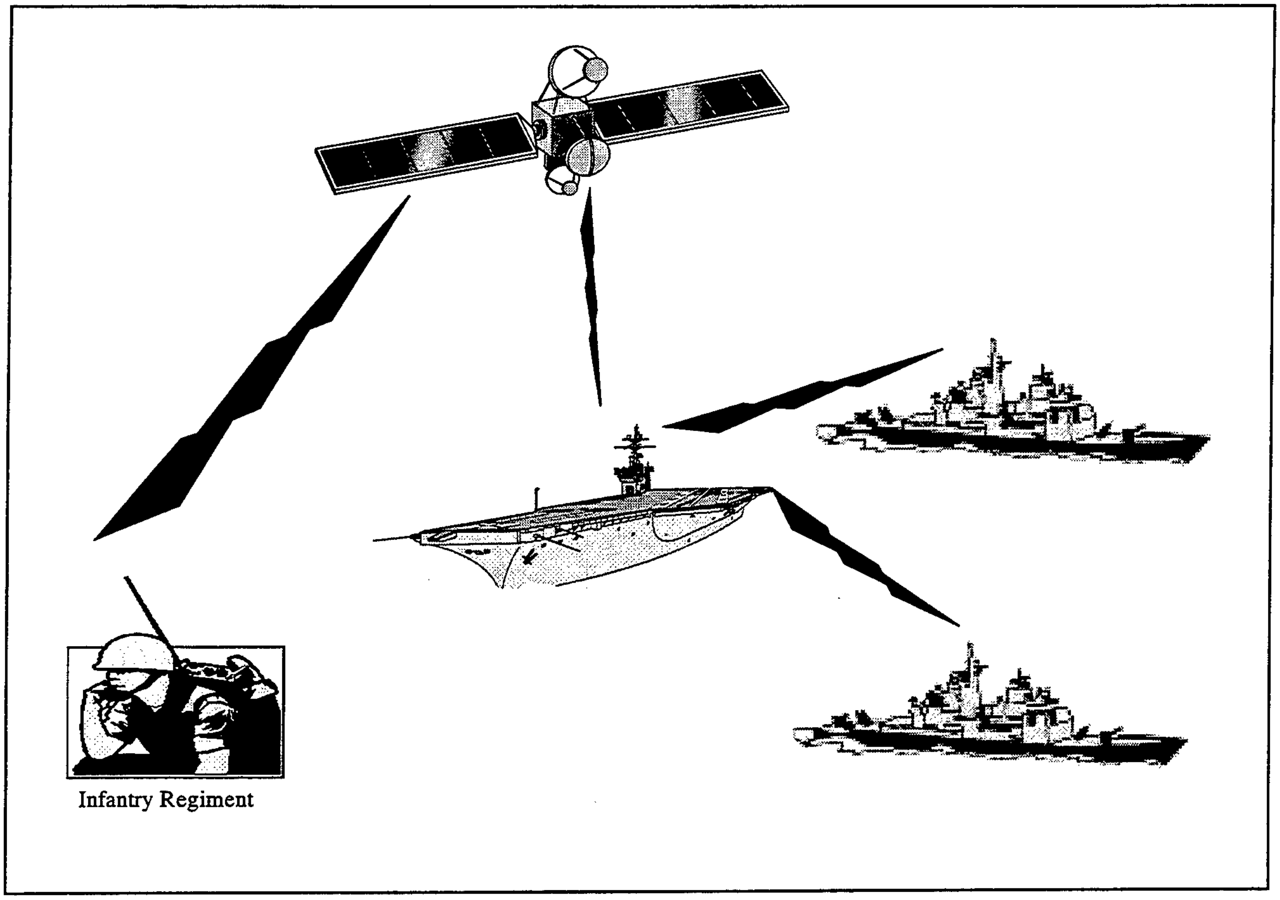

Figure 22. ELB NSFS Architecture.

b. User Group

The user group represents an infantry regiment (see Figure 23). The regiment is composed of three battalions with each battalion having three companies. Thus, an infantry regiment is comprised of nine companies (see Figure 19). Three platoons of three squads each make up an infantry company for a total of 81 squads in this model. The Marine Company icons represent nine squads each.

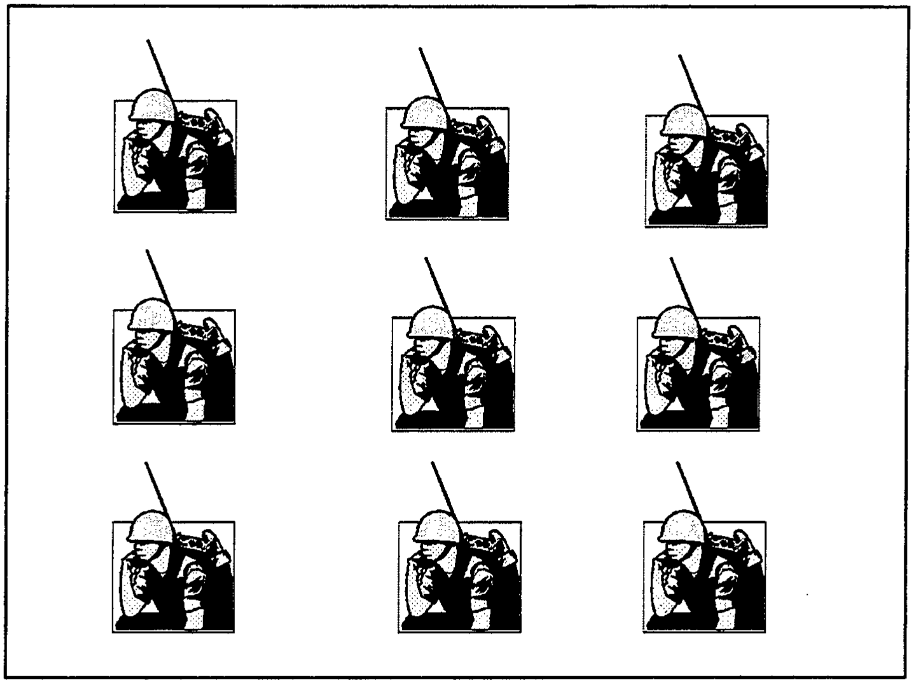

Figure 23. Modeled Infantry Regiment in Extend. [Ref. 51]

These squads are sending out a 256-bit POSREP message every five minutes and a 700-bit SITREP every 15 minutes. Ten squads send CFF messages (750-bits) every minute for 15 minutes at various times while in firefights. The POSREP and SITREP messages are sent to decision blocks for differentiation between routine and CFF messages. Routine messages are then sent to exit blocks. The time delays in the user block are the message length divided by the 2.4 kbps Iridium bandwidth. When the message leaves the program block, 18 bits are added to each message for encryption and IP addressing.

c. Satellite Block

The satellite picture (see Figure 24) represents the Iridium LEO system modeled in a hierarchical block (see Figure 25). This block pulls messages through the satellite system to the ship.

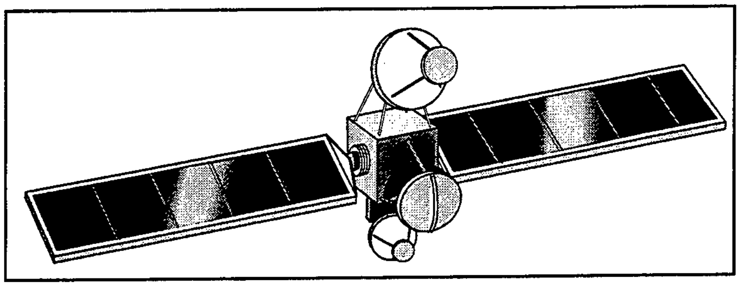

Figure 24. Satellite Hierarchical Block.

Figure 25 is the window that is called up when the satellite icon is "clicked-on." The messages are sent to a queue, where they wait to be pulled from the "Access" block. Once messages are pulled, a time delay is applied to the messages that

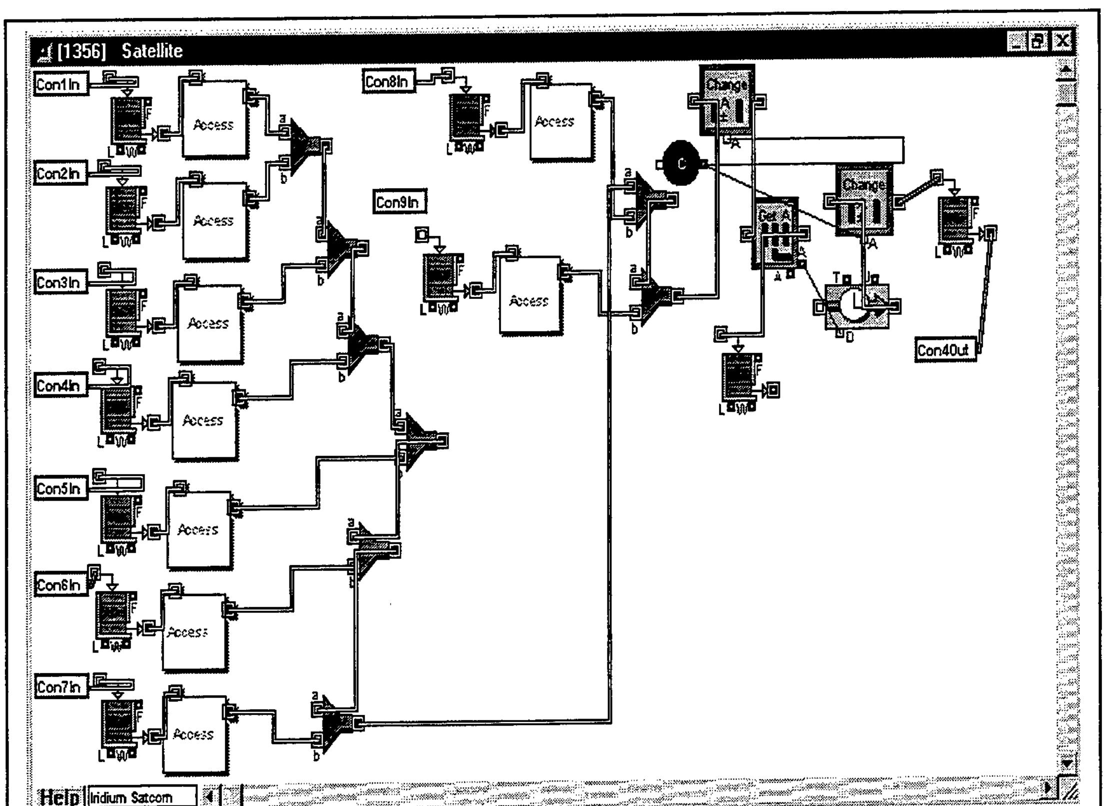

Figure 25. Iridium LEO System Modeled in Extend. [Ref. 51]

is directly proportional to the message size divided by the bandwidth, 2.4 kbps. The "Access" block (see Figure 26) is designed to make the modeled LEO system realistic in the sense that a call has a probability of not getting connected. A random number probability block is inserted to give calls a 98% chance of completion. Two percent of the calls will be returned through the block for call completion and a time delayed is applied to model this retransmission.

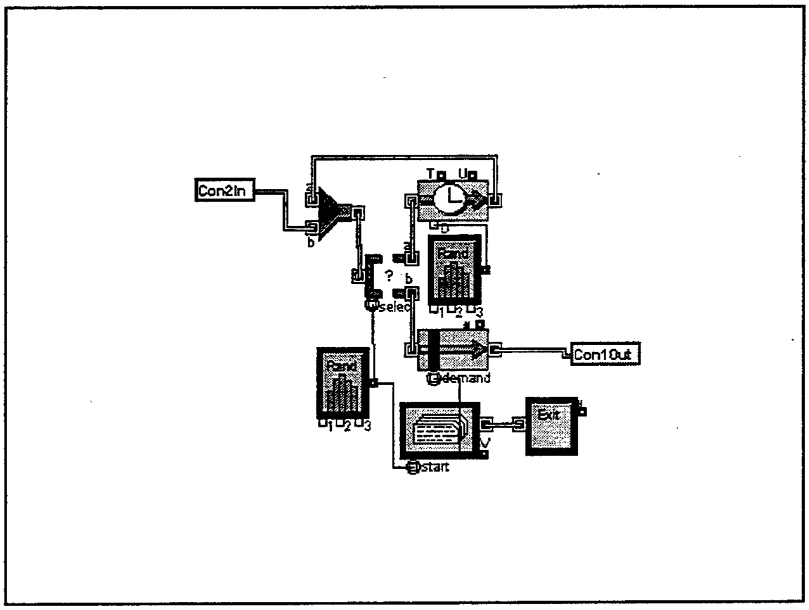

Figure 26. "Access" Block for LEO modeled system. [Ref. 51]

d. LAWS Block

CFF messages enter LAWS via the narrow-band satellite link into the main LAWS terminal in the SACC onboard the command ship (see Figure 27). The message is then sent through various time delays in sequence to match target with munitions and check the status of firing platforms (see Figure 28).

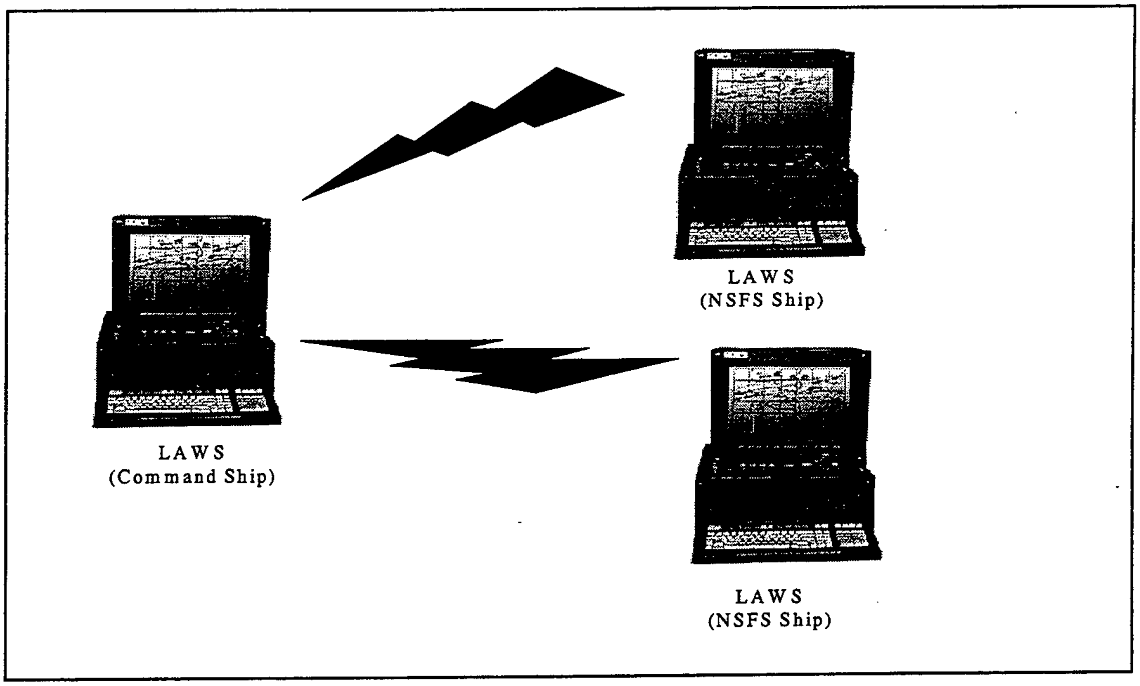

Figure 27. LAWS NSFS Architecture

Once LAWS has matched the CFF target with the appropriate munitions, and the message passes through the time delay block to check the platform status, the message is sent to the appropriate firing platform. To simulate the platform status changes the message has a 5% chance of being returned due to the unavailability of a particular munitions required. When the message makes it through the delay blocks and the appropriate firing platform processes the CFF message, the message is then sent to an exit block. This process occurs for every CFF message. As mentioned earlier, the POSREP and SITREP messages are sent to an exit block early in the process.

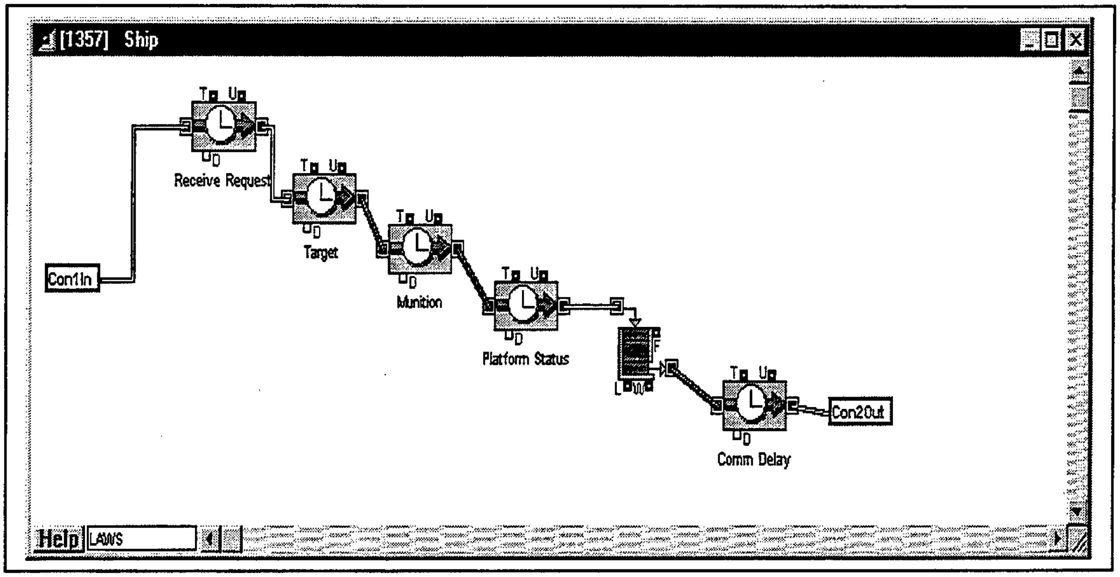

Figure 28. LAWS Modeled in Extend. [Ref. 51]

C. RESULTS

The models were run ten times each. In each run, 100% of the messages were delivered successfully. Only the 750-bit CFF messages were processed through the entire fire support communication architecture. The POSREP and SITREP messages were given early exit blocks. The average delay times of all the CFF messages were added together for each separate architecture and the average of these delays were used for input into the Joint Conflict and Tactics Simulation. Table 4 displays the results of the model runs. Delay times are the averages of the ten runs. The naval gunfire support architecture produced an average delay time of 14.7 minutes for a Battalion Landing Team (BLT) size force. The ELB NSFS architecture produced an average delay time of 9.1 minutes for a Regimental Landing Team (RLT) size force. These are the two times that were entered into JCATS as the time it takes for the Forward Observer to successfully get a CFF shot.

	NGF Architecture	ELB NSFS Architecture
Total Messages Sent	301	894
Total CFF Messages Sent	58	161
% CFF Messages	19.3 %	18.0 %
Average Message Time	14.7 minutes	9.1 minutes

Table 4. Extend Model Results.

D. SUMMARY

The two delay times were the pieces of information desired to be gained by using Extend for input into JCATS. Although there was a slight difference in the percentage of CFF messages in the NGF architecture compared to that for the ELB NSFS architecture, the ELB architecture contained more information sorting. Both architectures realistically modeled the processes for obtaining sea-based fire support. Using data gathered in previous exercises was invaluable for making the results of the model realistic.

VI. COMBAT SIMULATION MODELING

This chapter examines potential changes in an amphibious assault scenario using the Joint Conflict and Tactical Simulation (JCATS) Combat Simulation Model to simulate a portion of Exercise KERNEL BLITZ (KB). The call for fire delay times calculated using Extend were inserted into JCATS to determine their affect in a combat scenario.

A. JCATS COMBAT MODEL

JCATS was developed by Lawrence Livermore National Laboratory. It evolved from a merger of the Joint Tactical Simulation (JTS) and the Joint Conflict Model (JCM). JCATS is a multi-sided, high resolution, entity level combat simulation model used for throughout the Department of Defense (DOD) and other U.S. government agencies for combat and conflict training, exercises, analysis, experiments, and rehearsals. JCATS can model strategic through tactical levels across the broad spectrum of war, from Joint Task Force head-to-head engagements to individual conflicts in operations other than war. Some of the most important features and capabilities of JCATS include:

- Amphibious landings and submarine play
- Platforms blocking line of sight(LOS)
- Four levels of acquisition
- Peripheral acquisitions
- Detailed trafficability model
- Multi-story urban operations with windows, doors and interior direct fire engagements with solid object interaction from buildings
- Precision guided weapons with supporting laser spotting

- FO to direct support asset automatic call for fire
- Detailed ROE settings
- Dynamically controlled non-homogeneous aggregation/disaggregation and mount/dismount functions
- Detailed human factors including fatigue, secondary suppression and fratricide. [Ref. 53]

B. OBJECTIVES

Using a large-scale U.S. Marine Corps and Navy amphibious exercise as the operational framework for the model, the JCATS simulations in this study will attempt to capture the unique features of amphibious combat operations and emerging technologies for littoral combat in the next century.

The objective of this simulation is to examine the impact of changes in sensor-to-shooter delay times on the combat effectiveness of ground forces. Using the current call-for-fire system as the baseline, Naval Surface supportability will be considered. Interaction between the performance characteristics is expected. As the simulations are conducted, a preliminary analysis may indicate the need to reduce the number of independent characteristics that require a full examination. Future research to gain additional insight into the affects of sensor-to-shooter delay times in amphibious operations may be based on the results of this thesis.

C. MODEL DESCRIPTION

1. Fleet Battle Experiment Echo (FBE-Echo)/KB

The future of naval warfare is being shaped in the Fleet Battle Experiments. The overriding purpose of these experiments is to test innovative concepts and technologies in

a real-time battle scenario. In particular, FBE-Echo will test future capabilities in both asymmetrical and traditional maritime environments. [Ref. 54] FBE-Echo will be conducted in conjunction with Kernel Blitz (KB), an umbrella exercise for a series of naval force operational events during 1999 on the West Coast of the United States. KB "Prime" is a traditional large-scale amphibious assault exercise, which will exercise a real-world contingency plan. For the purposes of this thesis, the actual amphibious assault portion of KB will be referred to as KB-99. The analysis conducted in this thesis used the first phase of the tactical operations during KB-99 of one of the U.S. Marine infantry battalions, Second Battalion, Fifth Marine Infantry Regiment (2/5), as the tactical framework for the simulated scenarios.

2. KB-99 Political and Military Background Details

The KB-99 scenario is based on U.S. Military Forces conducting littoral operations against a generic third world country, Orange, and Orange supported rebels in country Green. These countries are located on the southwestern coast of the United States. The country of Orange consists of southern California, Arizona, and Nevada. Green consists of northern California. The scenario's geopolitical situation is intended to be representative of one which could occur in 1999 in a sensitive region, with hostilities eventually spanning to low-mid intensity conflict.

Orange is a religious oligarchy, generally hostile towards Western governments and views Western society as corrupt and immoral. Orange has supported insurgency movements in Green that support reunification with Orange. These movements include groups that use violence and terrorism in country Green. Orange views U.S. military operations in the area as a challenge to its own goal of regional hegemony. Green has

been democratic since its inception. It has established good relations with the Western Powers and is a strong supporter of U.S. activity in the region.

Militarily, Orange has the capacity to secure regional hegemony if unchecked. This will threaten U.S. vital interests in oilfields, exports, and manufacturing sites nearby. Neighboring countries posses the technology for inter-continental ballistic missiles (ICBM), which if captured by Orange, will have a devastating effect on the regional balance of power and U.S. economic interests. Orange's current missile and mining capabilities allow them to threaten sea lanes. Intelligence estimates indicate that Orange has chemical and biological warfare capabilities. Their ongoing development of these capabilities has bolstered their recent actions.

3. Current Military Situation

Recent Orange naval operations in the Straits of Barbara, increased tensions and a forward deployed force consisting of an Amphibious Ready Group/Marine Expeditionary Unit (MEU) and Carrier Battle Group was ordered to the region. Orange insurgents intensified activity. The Green capital, Francisco City, was hit by a major earthquake and insurgents seized opportunity to interfere with commercial shipping in Francisco Bay. Green requested U.S. assistance, and U.S. Forces began humanitarian and peace operations in support of Green in Francisco Bay area. Orange retaliated by attacks on military and civilian shipping off the coast of Southern California. U.S. military forces were tasked to open sea lanes and neutralize Orange's ability to militarily influence neighboring nations and threaten U.S. interests in the region. U.S. air and sea offensive began against Orange missile sites, weapons of mass destruction facilities, and mine facilities. By April 10, strategic and operational naval fires commenced against Orange

armored forces, airfields, logistics bases, and command and control sites. Preparation has begun for the seizure of San Pendleton Island (a notional island consisting primarily of Camp Pendleton, separated from the mainland by approximately 10 miles) to facilitate the introduction of follow on forces (see Figure 29). [Ref. 54]

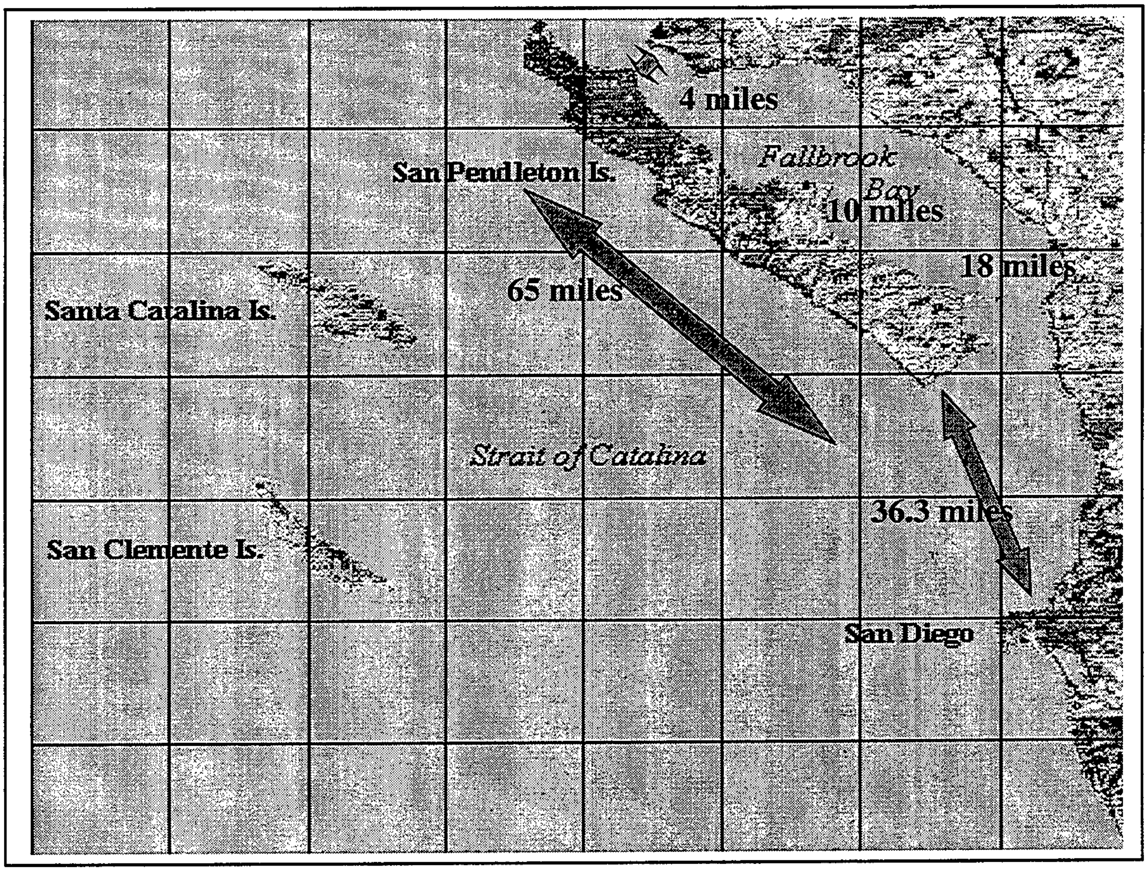

Figure 29. San Pendleton Island. [Ref. 55]

4. Amphibious Assault Plan

Regimental landing Team One (RLT-1) consists primarily of three infantry battalions, a tank company, an artillery battery and supporting attachments. RLT-1 is assigned the mission of seizing RLT OBJ A, neutralizing enemy forces, and securing

cross-channel sites in order to facilitate the rapid introduction of follow on forces. RLT-1's plan includes a surface assault in Amphibious Assault Vehicles (AAVs) by (2/5), a helicopter assault by First Battalion, Seventh Marine Infantry Regiment (1/7) and landings of the remaining forces by landing craft.

5. 2/5 Scheme of Maneuver

The combat scenario in this thesis is generally based on the actual exercise mission and activity of 2/5, its attachments, and the combat activity closely tied to 2/5's maneuver during KB-99 through the first phase of the operation.

The operations by 2/5 were preceded by the landing of a platoon of Light Armored Vehicles (LAV) via Landing Craft Air-Cushioned (LCAC) with the battalion reconnaissance teams. Therefore, the beach area is considered clear of enemy forces. Golf Company 2/5 (G 2/5), lands across Red Beach and moves to an assembly area near the entrance to Las Pulgas Canyon. Echo Company 2/5 (E 2/5) moves immediately to clear the high ground west of Las Pulgas Canyon, generally along Piedra de Lumbra Canyon.

Once this high ground is cleared, G 2/5 clears Las Pulgas Canyon and establishes a support by fire position southeast of RLT Objective A. E 2/5 then attacks to seize RLT Objective A. G 2/5 and the remaining battalion elements consolidate near the objective and prepare for the next phase (see Figure 30).

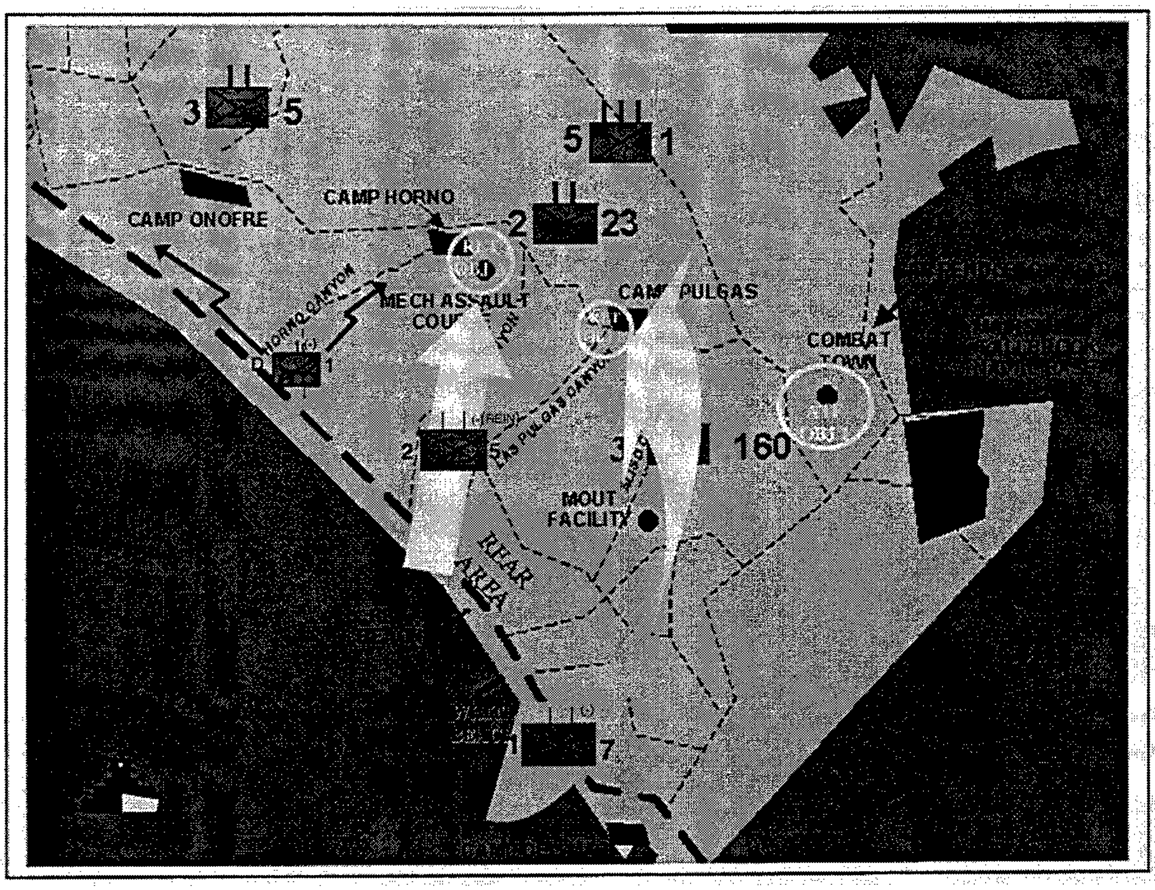

Figure 30. KB-99 Amphibious Assault Graphical Depiction

The following is a brief description of the primary activities of each unit in the scenario:

G 2/5:

- Become main effort
- At H-hour, Conduct amphib assault across red Beach and destroy enemy near RLT obj 1.
- Establish Assembly Area near checkpoint 73.
- Become supporting effort

- On order, clear Las Pulgas Canyon.
- Establish Support by fire position near checkpoint 9.
- On Order, establish Battle Position near Checkpoint 81A, oriented WNW to prevent enemy penetration from Horno Canyon.

E 2/5:

- Become Supporting effort.
- At H-hour, Conduct amphib assault across red Beach, following in trace of G Company, and move immediately to checkpoint 10.
- On order, clear high ground west flank of Las Pulgas Canyon in order to prevent enemy interference with main effort's movement up Las Pulgas Canyon.
- On order, become main effort.
- Attack along and neutralize enemy near RLT obj 2 in order to prevent enemy movement along Basilone Rd.
- On order, consolidate near RLT obj 2, protecting right flank of battalion position.

81mm Mortar Platoon:

- At H-hour, land on Red Beach.
- Follow in trace of E Company and establish firing positions to support maneuver elements.
- Displace by section to provide fires in support of attack on RLT obj 2.
- On order, displace to near RLT obj 2 and provide fires in support of consolidation.

- Initial firing positions near grid 592855.
- Secondary firing positions near grid 591899.

Each simulation scenario models the combat operations of 2/5 from the beach to the first major objective. The blue side represents the U.S. Forces and the red side represents country Orange Forces. The blue forces are generally aggregated to the platoon level, and consist of two mechanized infantry companies, weapons company assets, and naval surface fire support (NSFS) assets. In each scenario, they are opposed by red forces consisting of elements from a mechanized infantry battalion with soviet block weapons and equipment, damaged and dispersed from several weeks of intense bombardment by naval and air forces. The red forces are generally dispersed in squad sized elements, deployed in the general area of their parent company. The red forces delay and defend until they can determine which canyon the blue forces are attempting to penetrate. Their intent is to then rapidly reorganize their remaining forces for a counter-attack to destroy the blue beachhead.

D. SIMULATION RESULTS

The scenario described above remained constant throughout all simulation runs; therefore allowing the delay times determined previously to be the primary variable. The delay time from sensor-to-shooter was set initially to model the current call for fire system. The delay time then was altered to match those of the proposed system. Each scenario was run ten times, using the JCATS Simulation Executive batch program.

We chose to condense the JCATS simulation results into four different categories. We consider these to be are the measures of effectiveness pertinant to this thesis for the given scenario. Table 5 illustrates the four MOE's chosen, while the following is

description of each MOE and the results concerning each. The DDG platform was used in the model to represent NSFS.

		First DDG shot	Last DDG shot	Total Run time	# DDG shots
14 Minute Delay Time					
Run 1		47.04	162.93	182.92	13
Run 2		49.88	178.95	191.97	13
Run 3		25.75	214.27	214.27	13
Run 4		47.92	170.68	192.2	13
Run 5		76.45	160.27	196.52	10
Run 6		44.69	187.32	191.86	14
Run 7		48.77	180.1	193.79	15
Run 8		62.8	177.54	191	10
Run 9		51.71	175.53	189.72	10
Run 10		27.89	172.62	189.81	18
		48.29	**178.021**	**193.406**	**12.9**
9 Minute Delay Time					
Run 1		9.62	182.76	191.44	22
Run 2		9.5	182.16	189.88	22
Run 3		10.34	183.75	191.65	21
Run 4		9.36	182.93	191	20
Run 5		9.61	192.09	193.36	21
Run 6		9.43	181.66	192.53	22
Run 7		9.59	190.17	193.23	20
Run 8		9.58	181.5	191.07	20
Run 9		9.67	180.19	189.99	21
Run 10		9.89	189.45	190.55	17
		9.659	**184.666**	**191.47**	**20.6**

Table 5. JCATS Simulation Results.

1. Time of first DDG shots fired

This MOE represents the time during the scenario that the first NSFS assets were used to support the mission. The results show a significant difference (38.6 minutes

average) between the two variable delay times used. It was determined that this occurred because the delay time for the first ten runs was so long that organic fire support assets were better suited to complete the initial fire support missions in a more timely manner.

2. Time of last DDG shots fired

This MOE represents the time during the scenario that the last NSFS assets were used to support the mission. For these numbers to be usable they must be combined with the total run time of the scenario. The results show a slight difference (8.6 minutes average) between the scenarios. It was determined that this is also directly related to the unacceptable length of 14 minutes delay time. The scenario was forced to complete the mission using organic fire support assets because the communication delays times were too long for NSFS to be used late in the scenario.

3. Total Run Time

This MOE represents the total minutes it takes to complete the mission/reach the objective. The results show a slight advantage (1.9 minute average) is gained when using the proposed communication architecture. We feel that this time will continue to increase with increases in the fidelity of the JCATS model.

4. Number of DDG shots fired

The MOE represents the total number of times the surface ships were called upon and actually put rounds on target. The results show a difference of almost 8 fire mission per scenario. We determined this shows that the effectiveness and more importantly the usefulness of Naval Fire Support significantly increased with a faster sensor-to-shooter communication structure.

Clearly the results show that the delay time of the sensor-to-shooter communication structure does affect mission accomplishment. With longer communication delays the mission was still accomplished, but other fire support assets were required and the mission took slightly longer. This will affect follow on mission accomplishment under the OMFTS umbrella. Ground forces will rely on naval assets in the littoral regions.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

OMFTS and STOM seek to extend the littoral battlespace by placing emphasis on sea-based fire support and command and control. Maximizing the use of naval surface fire support for these advance doctrinal concepts requires OTH communications. Man-portable high frequency communications can reach the distances defined in OMFTS (100 miles OTH and 200 miles inland) but may be spotty due to skip zones. Also, HF communications will not provide the digital communications capability that technology provides in today's world. Low earth orbiting satellites provide worldwide coverage, and digital communications, accessible from the remotest areas.

Advances in the fire support systems, Land Attack Warfare System, and Advanced Field Artillery Tactical Distribution System, require that a digital communications network is used. OMFTS and STOM require a reliable OTH communication network. The ability of PalmELVIS to provide call-for-fire messaging, digital mapping and imagery, and GPS location must be exploited. The fact that these functions fit in a palm-size computer that are inter-operable with LAWS, AFATDS, and GCCS provides Marines with an extremely light-weight communications suite. PalmELVIS using an Iridium telephone provides forces improved fire support capable of communicating anywhere in the world.

As researched and illustrated in this thesis, this fire support architecture (see Figure 30) greatly reduced the time for a "shot out." The current naval gunfire procedures and architecture resulted in a time of 14.7 minutes. The new architecture using PalmELVIS, AFATDS, LAWS, and the Iridium LEO system resulted in a time of

9.1 minutes. This is a 64.5% reduction in time. This time had a direct impact in accomplishing objectives on land.

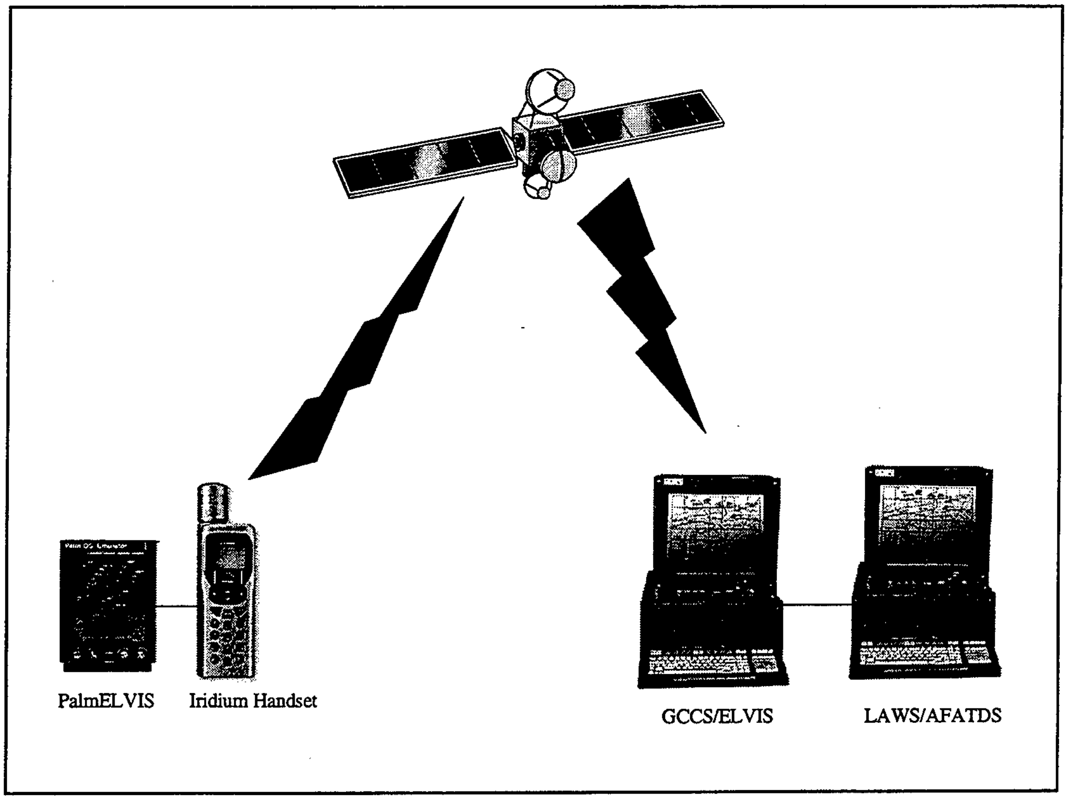

Figure 31. Proposed ELB Fire Support Communication Architecture.

B. FUTURE RESEARCH

This thesis has identified many areas for future research. This study used the results of the Hunter Warrior exercise and an ITT simulation to gain insight into information exchanges for calls-for-fire. This area needs to be investigated further to find out appropriate information exchanges in terms of amount of messages transferred, message sizes, and frequency. Communication models can be developed using this information that will aid planners by identifying critical vulnerabilities in a network.

The communication architecture models developed for this thesis can be built on and improved. This research used the Extend software to model the current naval gunfire architecture and the authors' proposed ELB naval surface fire support architecture. These models can be expanded or future research could use a more powerful communication modeling software such as OPNET. Valuable information concerning delay times, collisions, and network performance can be gained from communications modeling. The use of combat simulations and the ability to input communication effects provides another vital area of research. By modeling systems before acquiring them, their impact on the battlefield can be viewed.

Finally, the military applications of low earth orbiting satellite systems must be studied further. These systems will be able to provide greater bandwidth in the future. The introduction of Teledesic in 2003, able to provide T1 capability to dismounted users, provides the military great opportunities. New munitions with greater ranges will provide all Marines the ability to call in fires from the sea. LEO systems can be exploited for Marines to connect to these firing platforms from any terrain.

C. CONCLUSION

Sea-based fire support must be improved to make OMFTS and STOM a reality. The introduction of the AAAV and the MV-22 Osprey will increase the speed that Marines can reach their objectives, but they cannot accomplish their missions without fast, reliable, and "all-weather" naval surface fire support. The Extended Range Guided Munition (ERGM), Tactical Tomahawk, and the Land Attack Standard Missile (LASM), will provide Marines the munitions necessary to engage a wide range of targets well inside the ELB umbrella. Without a fast and reliable fire support communications

architecture, the new doctrinal concepts and munitions will be wasted. A fire support architecture for extending the littoral battlespace that can exploit available and emerging technology will serve as the backbone for the littoral doctrines.

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